MAINTENANCE TECHNICAL ADVISORY GUIDE
Volume I – Flexible Pavement Preservation
Second Edition

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Office of Pavement Preservation
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PREFACE

Pavement preservation is becoming more and more important in preserving the conditions of the national highway system. More than 1.75 trillion dollars have been invested in the highway system, managing and preserving this investment is increasingly the goal of highway agencies around the country. More and more agencies are realizing the benefits of having a sound pavement preservation program. These benefits include improved pavement performance, increased mobility and roadway safety, overall improved customer satisfaction, and reduced life-cycle costs.

The California Department of Transportation (Caltrans) has been a leader in promoting and advancing the pavement preservation technology. Considerable efforts have been devoted in this area. In 2001, Caltrans initiated an effort in developing a maintenance technical advisory guide (MTAG) for flexible pavement. The intention of the guide was to provide technical and uniform guidelines to Caltrans personnel in their pavement maintenance and preservation activities. The first edition of the MTAG for flexible pavements was developed in 2003 and the Federal Highway Administration is currently developing a web-site for sharing the knowledge contained in this guide.

To obtain the most current technology and technical expertise from various agencies and industry, Caltrans established the Pavement Preservation Task Group (PPTG), a partnership between Caltrans, industry, local agencies and academia to work on important pavement preservation issues that related to both the flexible and rigid pavements. Subtask groups focusing on specific areas of expertise were established and they have provided information in support of this document.

As the paving technologies and materials science advances, new innovations in pavement preservation have emerged. This second edition was developed to update the topics covered in the first edition with the most current information and to include the new innovations and new pavement preservation treatment technologies being used in the paving industry. Like the first edition, the second edition addresses maintenance strategies related to the flexible pavements and is designed for several levels of use, ranging from general instruction to specific work practice descriptions. It should be of use to District Maintenance Engineers, Maintenance Supervisors, Superintendents, and Field Personnel. Construction personnel and designers may also find the information useful.

The second edition of the MTAG for flexible pavement preservation consists of thirteen chapters. Chapter 1 is introduction, presenting a brief overview and purpose of pavement preservation, a brief discussion of common distresses found in flexible pavements on California's roadways. Chapter 2 describes the materials used in maintenance treatments. Chapter 3 presents a framework for strategy selection process for flexible pavement maintenance and preservation treatments. Chapters 4 through chapter 13 provide a detailed description of various treatments that Caltrans has been using to maintain and preserve the flexible pavements. These treatments include the following:

- Crack Sealing, Crack Filling, and Joint Sealing
- Patching and Edge Repair
- Fog and Rejuvenating Seals
- Chip Seals
- Slurry Seals
- Microsurfacing
- Thin Maintenance Overlays
- Bonded Wearing Courses
- Interlayers
- In-Place Recycling

This advisory guide is intended to serve as a comprehensive, useful reference. The document will be updated and revised as new information become available.

ACKNOWLEGMENTS

The development of the MTAG has been under the technical direction of Dr. Shakir Shatnawi, Chief of the Office of Pavement Preservation. The document was reviewed by Caltrans Maintenance Personnel, the Pavement Preservation Task Group (PPTG), and the Pavement Standards Team (PST). For questions on the guide, please contact:

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The PPTG reviewed the first edition of the MTAG and provided many technical comments. These comments set the stage for the second edition. The co-chairs of the PPTG for flexible pavements are Dr. Shakir Shatnawi from Caltrans and Gary Hildebrand from industry. The PPTG for flexible pavements consists of the following subtask groups:

Subtask Group	Subtask Group Caltrans Co-Chairs/Champions	Subtask Group Industry Co-Chairs/Champions
Binders	Kee Foo	Edgard Hitti
Chip Seals	Shawn Rizzutto	Joe Platt
Crack Seal/Joint Re-Seal	Karen Bonnetti	Lowell Parkison
Education	Larry Rouen	Brandon Milar and Larry Scofield
Fog seals/rejuvenators	John Fox	Bob McCrea
Innovation	Joe Holland	Scott Metcalf and John Roberts
Integrating Pavement Preservation with PMS	Susan Massey	David Peshkin
Pavement Management-Local Agencies	Sui Tan	Margot Yapp
Interlayers	Khalid Ghuzlan	Scott Dmytrow
Patching and Repair	John Poppe	Paul Noring
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Slurry Seal/Microsurfacing	Hamid Saadatnejadi	Steve Olsen
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Thin Overlays	Cathrina Barros	Skip Brown
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The pavement preservation task group co-chairs have provided technical assistance and review comments at various stages of the second edition. Their assistance is gratefully acknowledged.

CHAPTER 1 INTRODUCTION

1.1 OVERVIEW

This chapter presents an overview of pavement preservation purpose, concept, benefits, and pavement preservation treatment selection and the optimum timing for a treatment. This chapter also provides a discussion on the fundamentals of flexible pavements, which provides a basic understanding of the factors affecting flexible pavement performance. A brief description of various distresses and distress mechanism associated with flexible pavements is also provided.

1.2 PURPOSE OF PAVEMENT PRESERVATION

In the simplest term, the purpose of pavement preservation is to keep good pavements in good or near new conditions by applying the right maintenance strategies at the right time to extend pavement life and preserve investments. This section briefly describes the definition, concept, benefits of pavement preservation and importance of treatment selection and the optimum timing for the treatments used.

1.2.1 Definition

Pavement preservation, as defined by the FHWA, is a program employing a network level, long-term strategy that enhances pavement performance by using an integrated, cost-effective set of practices that extend pavement life, improve safety and meet motorist expectations (FHWA, 2005). A pavement preservation program consists primarily of three components: preventive maintenance, minor rehabilitation (restoration), and some routine maintenance (FHWA, 2005). A pavement preservation program does not include pavements that require major rehabilitation or reconstruction.

1.2.2 Pavement Preservation Concept

Pavement preservation is a proactive approach in maintaining the existing highways. An effective pavement preservation program addresses pavements while they are still in good condition and before the onset of serious damage. By applying a cost-effective treatment at the right time, the pavement can be restored almost to its original condition. The cumulative effect of systematic, successive preservation treatments is to postpone or delay costly rehabilitation and reconstruction (FHWA, 2005). The pavement preservation treatments restore the function of the existing system and extend its life by reducing aging and restoring its serviceability, not increase its capacity or strength. Performing a series of successive pavement preservation treatments during the life of a pavement is less disruptive to uniform traffic flow than long closures normally associated with reconstruction projects (FHWA, 2005).

Pavement preservation is not simply a maintenance program, but an agency program. Essentials for an effective pavement preservation program include agency leadership, a dedicated annual budget, and support and input from staff in planning, finance, design, construction, materials, and maintenance.

1.2.3 Benefits of Pavement Preservation

An effective pavement preservation program can benefit Caltrans by preserving the roadway network, enhancing pavement performance, ensuring cost-effectiveness by extending pavement life, and reducing user delays by delaying major rehabilitation or reconstruction projects. Some of these benefits may be noticed immediately and some may be realized over time (Galehouse, Moulthrop, and Hicks, 2003).

1.2.4 Treatment Selection and the Optimum Timing for the Treatment

Figure 1-1 shows how a flexible pavement would typically perform under traffic and with time (dotted line). Various types of treatment stages are also shown in the figure. It clearly indicates that the pavement preservation should be carried out at early stage of the pavement life while it is still in good conditions both structurally and functionally. If the pavement is not maintained effectively, it will eventually deteriorate to a point where the only choice is reconstruction which is the most costly option.

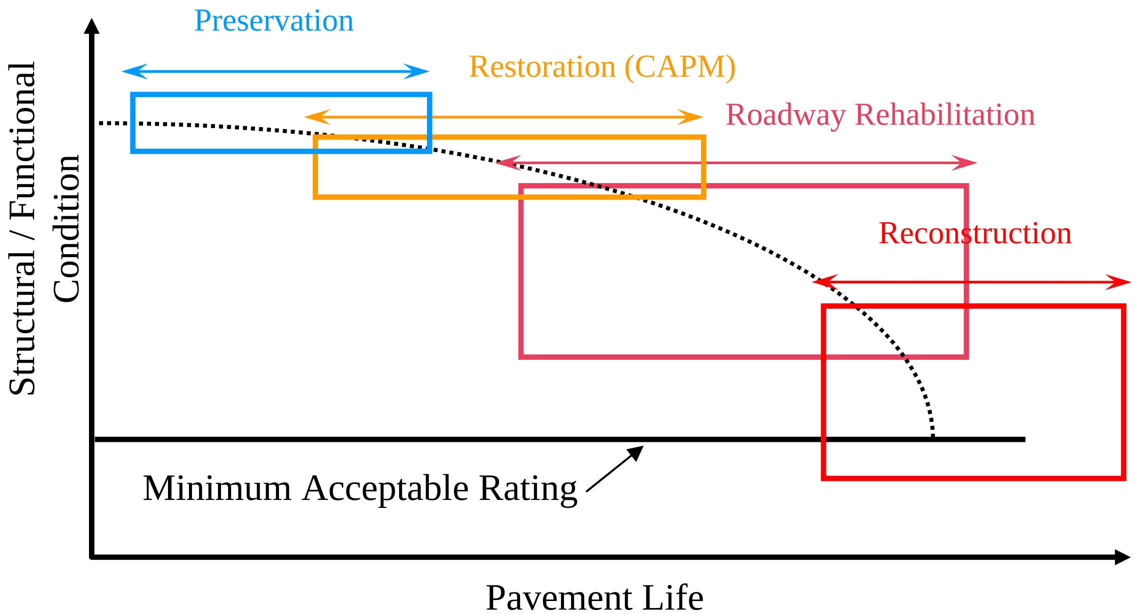

Figure 1-1 Typical pavement performance curve and maintenance/rehabilitation time

The timing of the application of the treatment has a significant influence on the effectiveness of the treatment in prolonging the performance of the pavement; therefore, applying the right treatment to the right pavement at the right time is of the core of pavement preservation. As indicated earlier, by applying cost-effective preservation treatments at the right time, the pavement can be maintained close to its original condition for a longer period of time. Timely application of a successive treatment can maintain the pavement in good condition and prolong the need for more expensive roadway rehabilitation and reconstruction strategies, as shown in Figure 1-2. This figure illustrates the concept of timely application of a treatment is important to maintain the existing pavement condition. The frequency of applying treatment will depend on the type of treatment that has been used and their life expectancy.

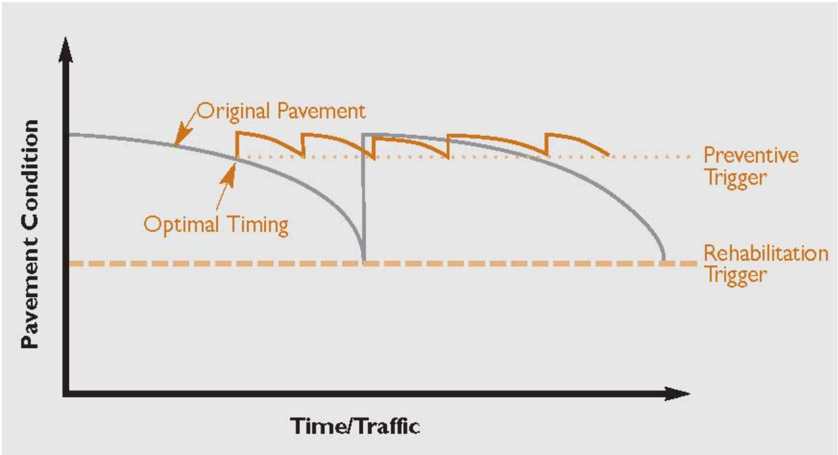

Figure 1-2 Concept of optimal timing for pavement preservation (Galehouse et al, 2003)

The timely application of preservation treatments is important as they not only improve pavement condition but also save money over the life of a pavement. Reconstruction or extensive dig-out and replacement strategies are far more costly than applying pavement preservation treatments. Figure 1-3 shows an example of the relative costs of preventive maintenance treatments in 1998 versus major rehabilitation treatments or reconstruction. When treatments are properly timed, preventive maintenance can produce savings over the life of the pavement (Zaniewski, 1996 and ISSA, 1998). In addition, subsequent maintenance treatments can be applied in a relatively quick manner resulting in fewer disruptions to the traveling public and less exposure to traffic for maintenance employees as compared with major rehabilitation or reconstruction activities.

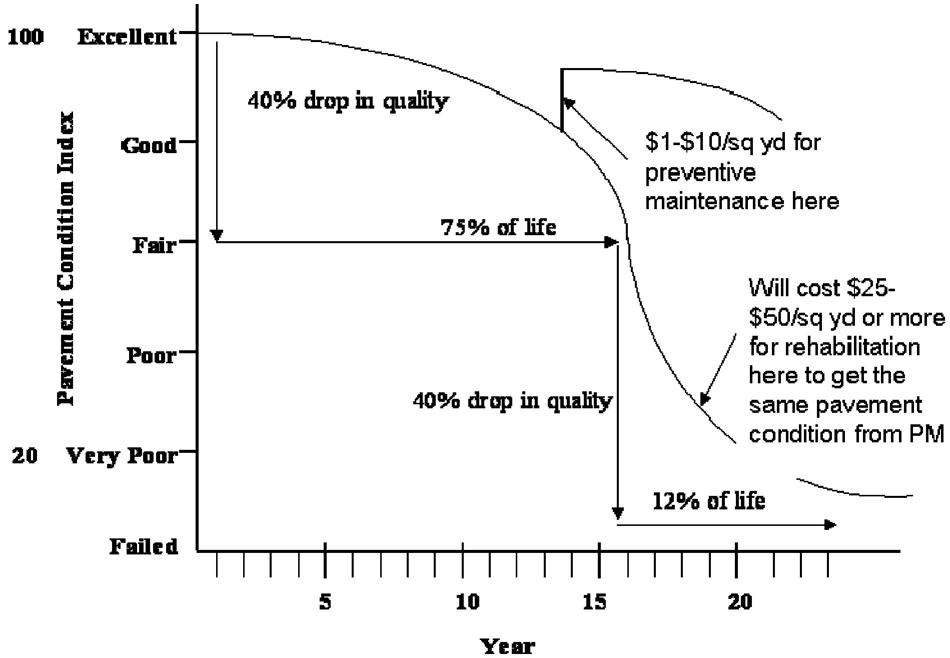

Figure 1-3 The Cost of NOT carrying out maintenance in a timely way

1.3 FUNDAMENTALS OF FLEXIBLE PAVEMENTS

1.3.1 Function of Pavements

Pavements are constructed to serve two primary functions. First , they serve the traveling public by providing a smooth, skid-resistant surface upon which vehicles may safely travel. Second, they must be structurally capable of withstanding the traffic and environmental loadings that are imposed upon them. A pavement may be considered failed if it does not adequately serve either one of these two functions.

Flexible pavements are one of several pavement types. They are the most common pavement types and are typically built with a hot-mix asphalt (HMA) surface or an asphalt surface treatment. A flexible pavement is very effective in providing load-carrying capacity, resisting distortion, providing a smooth riding surface, minimizing the intrusion of moisture from the surface, resisting traffic wear, and retaining anti-skid properties.

Flexible pavements typically consist of several layers of paving materials, as illustrated in Figure 1-4, which are built on natural soil, normally referred to as the subgrade soil. The top portion of the subgrade soil is compacted prior to placing the subbase or base. The subgrade soil ultimately carries all traffic loads. Thus, the function of a flexible pavement structure is to support a wheel load on the pavement surface and to spread or distribute the applied loads to the subgrade soil without exceeding its strength or that of various overlying pavement layers. Therefore, layers near the surface are generally constructed with paving materials of increasing quality and load-carrying capability.

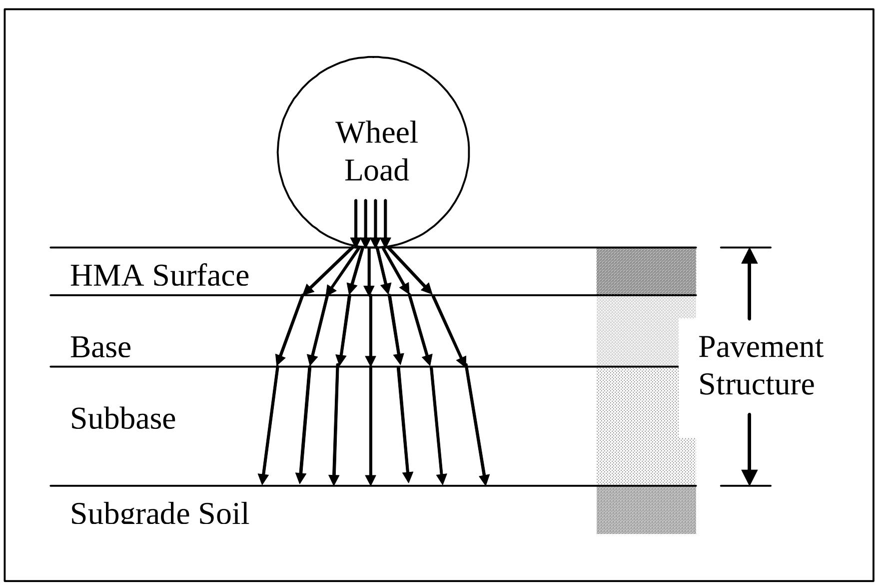

Figure 1-4 Typical flexible pavement structure and stress distribution (NHI, 2001)

1.3.2 Factors Affecting Pavement Performance

There are a number of factors that contribute to pavement distress and loss in performance. The key factors that can be affect pavement performance and/or impact pavement preservation treatment selection include:

- Subgrade Soil
- Pavement Materials Characteristics
- Traffic Loading
- Environment

Subgrade Soil

Pavement structures must rely upon the strength and stiffness of the underlying subgrade soil for support. As shown in Figure 1-4, one of the functions of a pavement structure is to distribute the stress from applied wheel loads to such an extent that the subgrade soil is protected from overstress. Because of this load distribution function, it is easy to understand why weak soils require thicker pavements than strong soils to provide the same protection against overstress due to traffic loadings.

From a pavement design and engineering standpoint, there are two general characteristics of the soil that are of interest, its classification and either its strength or stiffness. Soil classification provides the engineer with a good idea of the gradation and constituents of the subgrade soil. The strength of a material refers to the amount of load or stress it can withstand before failing (either through fracture or high deformation). The stiffness of a material refers to its capacity to resist deformation under applied loading. The two properties are distinctly different; however, they are highly correlated and often used as surrogates for one and other. The primary measures of soil strength include the California Bearing Ratio (CBR) and the unconfined compressive strength. The primary measures of stiffness are Hveem stabilometer (R-value) and elastic (or resilient) modulus. Although many of these measures have been adequate in the past for strength and stiffness characterization, the current trend is to consider more fundamental engineering properties, such as the elastic (or resilient) modulus. The resilient modulus is a measure of the pavement's response under load, and is thus better suited for long-term pavement performance prediction. Caltrans uses the R-value, unconfined compressive strength (for lime-treated subbases only), and the Gravel Factor (G_f) for pavement design purposes (Caltrans 2006).

Pavement Materials Characteristics

There are many materials that are used in the construction of a pavement. Typically, the individual ingredients or constituents fall under one of four different categories:

- Asphalt Cement
- Aggregate
- Modifiers for Asphalt Cement (e.g., Rubber and Polymers)
- Additives or Stabilizing Agents for Aggregates (e.g., Lime and Cement)

When the various ingredients are combined in proper proportions, they produce mixes (e.g., HMA, stabilized bases/subbases) that ultimately make up the structural components of the pavement. Obviously, high quality materials, good mixing and construction practices, and good quality control/quality assurance will help maximize the ultimate load-carrying capacity of the pavement.

Structural (or physical) characteristics of the pavement system have a significant impact on pavement performance. Structural characteristics for HMA pavements primarily include the layer types and their thicknesses. These characteristics can be controlled during the design and construction process. Another factor that influences pavement material properties and consequently affects pavement performance is the variation in material properties that occurs in construction and rehabilitation operations. For example, failure to achieve proper compaction, variable moisture conditions during construction, uniformity and quality of paving materials, and as-built layer thicknesses all directly affect performance.

Traffic Loading

Pavements are designed and constructed to withstand the stresses and strains caused by repeated wheel loadings that are sustained over the course of their life. Therefore, it is important to have a good knowledge of the amount of traffic loading expected on a pavement. The proper structure design of a pavement relies upon developing an accurate forecast of future loadings, which should include the following:

- Average Daily Traffic, ADT (initial number of vehicles per day)
- Future Projections (annual growth rate by vehicle type)
- Truck Factors or Load Equivalency Factors (to convert the distribution of vehicle loads into an equivalent number of load applications that can be used for design)
- Lane Distribution (percent of trucks in design lane)
- Directional Distribution (percent of trucks in design direction)

These factors are combined with the design period (up to 40 years for long-life pavements) to derive the 18,000 lb equivalent single axle load (ESAL) applications that must be sustained by the "design lane" (i.e., that lane of the pavement that carries the most ESAL applications and for which the pavement structure or overlay will be designed). The Caltrans flexible pavement design method converts the ESAL applications to a Traffic Index (TI) for pavement structural section design (Caltrans, 2006).

Environment

Moisture and temperature are two key environmental factors that have a significant impact on pavement performance:

- **Moisture:** Moisture enters a pavement structure through cracks in the surface, laterally from poor draining ditches, and from the underlying water table through capillary action. The presence of moisture in the soil and underlying layers of the pavement structure weakens those materials and thereby reduces their load-carrying capacity. The presence of moisture in an HMA layer can lead to a phenomenon known as stripping, which is the separation of asphalt cement from aggregate particles in the mix. Moisture in the soil in regions where freezing occurs can result in differential frost heave and thaw weakening. In addition, moisture changes in some clay soils can cause volume changes and pavement distortion and roughness. Because of the effects of moisture on pavement performance, significant attention should be given to drainage during pavement design and construction.

- **Temperature:** At high temperatures, asphalt cement softens and is more likely to experience permanent deformation (rutting) under wheel loading. At low temperatures, HMA will shrink (due to thermal contraction) and contribute to transverse (thermal) cracking. Also, at low to intermediate temperatures, HMA can become brittle and susceptible to fatigue cracking.

1.4 FLEXIBLE PAVEMENT DISTRESSES

Typical pavement structures include hot mix asphalt (HMA) layer(s), with or without any untreated or treated aggregate base layers, over the subgrade soil. Flexible pavement preservation typically includes thin overlays or seal coats.

In general, thin overlay, as defined in this Guide, is a non-structural layer and is applied as a maintenance treatment, either corrective or preventive. Seal coats are intended to improve the functional performance. The pavement distresses and distress mechanisms for flexible pavements can generally be classified into the following categories:

- Cracking
- Deformation
- Deterioration
- Mat Problems
- Problems associated with seal coats

Determination of applying a specific type of treatment will depend upon the types of distress, extent and severity of the distresses. In general, pavement preservation treatments should be applied to pavements with little or minor distresses to preserve the pavements while they are still in a good condition.

Distress photos shown in this chapter are from "*Guide to the Investigation and Remediation of Distress in Flexible Pavements*" (Caltrans, 2003) and "*Distress Identification Manual for the Long-Term Pavement Performance Program*" (FHWA, 2003).

1.4.1 Cracking

Longitudinal – Cracks that are approximately parallel to pavement centerline and are not in the wheel path. Longitudinal cracks are non-load associated cracks. Location within the lane (wheel path versus non-wheel path) is significant. Longitudinal cracks in the wheel path are normally rated as Alligator 'A' cracking.

Figure 1-5 Longitudinal Cracks

Fatigue – Cracks in asphalt layers that are caused by repeated traffic loadings. The cracks indicate fatigue failure of the asphalt layer. Hence, the term fatigue cracking is used. When cracking is characterized by interconnected cracks, the cracking pattern resembles that of an alligator's skin or chicken wire. Therefore, it is also referred to as alligator cracking.


Figure 1-6 Fatigue Cracks

Transverse – Cracks that are predominately perpendicular to pavement centerline and are not located over portland cement concrete joints.


Figure 1-7 Transverse Cracks

Reflective – Cracks in HMA overlay surfaces that occur over joints in concrete or over cracks in HMA pavements.


Figure 1-8 Reflective Cracks

Block – A pattern of cracks that divides the pavement into approximately rectangular pieces. Rectangular blocks range in size from approximately 0.1 square yard to 12 square yards.

Figure 1-9 Block Cracks

Edge – Crescent-shaped cracks or fairly continuous cracks that intersect the pavement edge and are located within 2 feet of the pavement edge, adjacent to the unpaved shoulder. Includes longitudinal cracks outside of the wheel path and within 2 feet of the pavement edge.

Figure 1-10 Edge Cracks

1.4.2 Deformation

Rutting – Longitudinal surface depression that develops in the wheel paths of flexible pavement under traffic. It may have associated transverse displacement.

Figure 1-11 Rutting

Corrugations – Transverse undulations appear at regular intervals due to the unstable surface course caused by stop-and-go traffic.

Figure 1-12 Corrugations

Shoving – A longitudinal displacement of a localized area of the pavement surface. It is generally caused by braking or accelerating vehicles, and is usually located on hills or curves, or at intersections. It also may have vertical displacement.

Figure 1-13 Shoving

Depression – Small, localized surface settlement that can cause a rough, even hazardous ride to motorists.

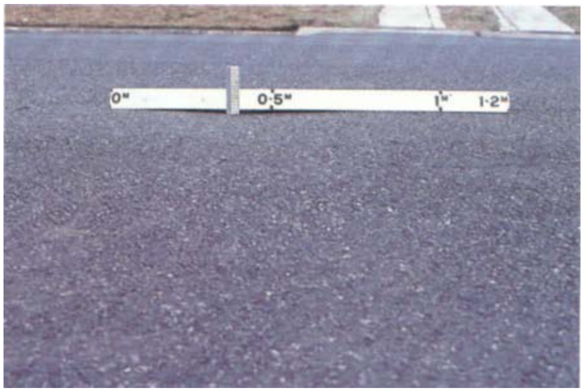

Figure 1-14 Depression

Overlay Bumps – In newly overlaid pavements, bumps occur where cracks in old pavements were recently filled. This problem is most prevalent on thin overlays.

Figure 1-15 Overlay Bumps

1.4.3 Deterioration

Delamination – Loss of a large area of pavement surface. Usually there is a clear separation of the pavement surface from the layer below. Slippage cracking may often occur as a result of poor bonding or adhesion between layers.

Figure 1-16 Delamination

Potholes – Bowl-shaped holes of various sizes in the pavement surface. Minimum plan dimension is 6 inches.

Figure 1-17 Potholes

Patching – Portion of pavement surface, greater than 0.1 sq. yard, that has been removed and replaced or additional material applied to the pavement after original construction.

Figure 1-18 Patching

Raveling – Wearing away of the pavement surface in high-quality hot mix asphalt concrete that may be caused by the dislodging of aggregate particles and loss of asphalt binder.

Figure 1-19 Raveling

Stripping – The loss of the adhesive bond between asphalt cement and aggregate, most often caused by the presence of water in asphalt concrete, which may result in raveling, loss of stability, and load carrying capacity of the HMA pavement or treated base.

Figure 1-20 Stripping

Polished Aggregate – Surface binder worn away to expose coarse aggregate.

Figure 1-21 Polished Aggregate

Pumping – Seeping or ejection of water and fines from beneath the pavement through cracks.

Figure 1-22 Pumping

1.4.4 Mat Problems

Segregation – Separation of coarse aggregate from fine aggregate as a result of mishandling of the mix at several points during mix production, hauling, and placing operations. Segregation leads to non-uniform surface texture and non-uniform density.

Figure 1-23 Segregation (HMA)

Checking – Short transverse cracks, usually 1 inch to 3 inches in length and 1 inch to 3 inches apart, which occur in the surface of the HMA mat at some time during the compaction process. The cracks do not extend completely through the depth of the course, but are only 3/8 to ½ inch deep.

Figure 1-24 Checking

Bleeding – Excess bituminous binder occurring on the pavement surface. May create a shiny, glass-like, reflective surface that may be tacky to the touch. Usually found in the wheel paths.

Figure 1-25 Bleeding (HMA)

1.4.5 Problem Associated Seal Coats

Rock Loss – Wearing away of the pavement surface in seal coats.

Figure 1-26 Rock loss

Segregation – Separation of coarse aggregate from fine aggregate as a result of mishandling of the mix at several points during mix production and placing operations. Segregation leads to non-uniform surface texture.

Figure 1-27 Segregation (seal coats)

Bleeding/Fat Spot – Excess binder occurring on the surface treated pavements. May create a shiny, glass-like, reflective appearance. Fat spots are localized bleeding.

Figure 1-28 Bleeding/fat spot (seal coats)

Delamination – Loss of portion of pavement surface treatment. Usually there is a clear separation of the surface treatment from the layer below.

Figure 1-29 Delamination (seal coats)

Distress types under each category along with primary mechanisms for each distress are summarized in Table 1-1. Note that many of these types of distress also occur on HMA patched or recycled surfaces and mechanisms for causing these distresses are similar to those of HMA.

Table 1-1 Distress Type and Mechanism

TYPE		MECHANISM
CRACKING	**Longitudinal**	Poorly constructed paving joint, shrinkage of surface layer due to temperature cycling or hardening of the asphalt. Longitudinal cracking can be load or non-load related depending on the location of the crack within the travel lane. Longitudinal crack in the wheel path also refers to the initial stage of fatigue (alligator) cracking. Note: longitudinal cracking due to thermal and/or shrinkage will be considered under the transverse and block-cracking categories.
	Fatigue	Repeated applications of tensile strain due to wheel loading cause the initiation (and propagation) of a crack at the bottom of the HMA layer. A secondary type of fatigue cracking is that which occurs in thick HMA layers from the top-down. This surface-initiated fatigue cracking is associated with the state of stress directly below a tire and usually takes much longer to appear than bottom-up cracking in thinner HMA layers.
	Transverse	Inadequate bonding between paving lanes due to poor construction techniques (improper joint compaction), shrinkage of asphalt surface due to low temperatures or hardening of asphalt cement, or reflective cracks caused by cracks below the surface. Transverse cracks caused by low temperature are referred to as thermal cracks which are due to contractive forces and restraint, supplied by 1) friction on the bottom of the HMA surface and 2) the continuity of the HMA layer itself, that causes the tensile stress to build up to such a point that it can exceed the tensile strength of the HMA layer thus initiating cracking.
	Reflective	Typically appears in an overlay as a result of movements in a crack or joint in the underlying pavement. Development is especially likely when the pavement below is a PCCP with long joint/crack spacings and poor load transfer.
	Block	Shrinking and hardening of the asphalt due to age and/or environment (temperature).
	Edge	Excessive vehicle loading (stress) at pavement edge. The problem is usually related to poor geometry, inadequate shoulders, and/or poor drainage near the pavement edge.

Table 1-1 Distress Type and Mechanism

Type		Mechanism
Deformation	**Rutting**	Excessive vertical compressive stresses on the HMA surface, base and subgrade soil causing non-recoverable permanent deformation in one or all layers in the pavement structure.
	Corrugations	Plastic movement in the HMA surface layer caused by traffic action on HMA with too much asphalt, too much fine aggregate, or smoothed course aggregate. Appearance is that of a washboard and it has a definite influence on ride quality.
	Shoving	Plastic movement in the HMA surface layer caused by traffic action on HMA with too much asphalt, too much fine aggregate, or smoothed course aggregate. The distress usually appears in localized areas and the deformation can be longitudinal as well as vertical.
	Depression	Localized consolidation or movement of the supporting layers beneath the surface course due to weakness or instability of the material.
	Overlay Bumps	Excessive uneven stress concentration at the crack caused by unstable crack filler, unstable HMA with low shear strength, and excessive moisture in the crack.
Deterioration	**Delamination**	Loss of bond between the surface and the layer below causing surface layer to be easily peeled off.
	Potholes	Traffic loads causing pavement disintegrates because of inadequate strength in one or more layers of the pavement, usually accompanied by the presence of water.
	Patching	Crack, settlement, or distortion in patched areas when the underlying cause of the original pavement defect is not corrected or that the utility trench was not properly backfilled forming a weak support underneath.
	Raveling	The result of a loss of adhesion between the asphalt binder and the aggregate causing the loss of material from pavement surface.
	Stripping	The presence of a prolonged high-moisture condition (together with an aggregate with a high-stripping potential) in asphalt bound layers leads to the debonding of the asphalt binder from the aggregate particles.
	Polished Aggregate	Surface binder worn away to expose aggregate due to traffic action and/or mix properties.
	Pumping	Seeping or ejection of water and fines from beneath the pavement through cracks or joints under the applications of heavy vehicle loadings.

Table 1-1 Distress Type and Mechanism

TYPE		MECHANISM
MAT PROBLEMS	**Segregation**	Improper mix handling during lay down of HMA causing coarse aggregate separated from fine aggregate and the compacted mix does not have desired density and uniformity.
	Checking	Primarily caused by two factors: excessive deflection of the pavement structure under compaction equipment and one or more deficiencies in the asphalt mix design. Incorrect mix design could result in a tender mixes that has very low resistance to deformation under horizontally applied shearing loads after compaction has been completed. The tender mixes normally resulted from a lack of inter-particle friction or shear strength and were generally material properties and/or construction related.
	Bleeding	Excessive asphalt in the mix relative to the void space in the mineral aggregate, therefore, the air voids in the mix are too low and the excess asphalt is forced to the pavement surface causing bleeding.
SEALS COATS	**Rock Loss**	Lack of bonding between aggregate and binder, plus traffic action causing rock breaking away from the compacted mixture. This problem occurs in chip sealed pavements.
	Segregation	Materials not properly mixed and placed during construction therefore not having a desired uniformity, strength and ability to sustain traffic action.
	Bleeding / Fat Spots	Due to excess binder.
	Delamination	Loss of bond between the surface treatment and the existing surface causing surface treatment material separated from the existing pavement surface.

1.5 DISTRESS TREATMENTS

One of the purposes of this guide is to provide guidance on selecting the most appropriate strategies to address various pavement distresses described earlier by applying pavement preservation treatments. Chapter 3 of this guide presents a framework for treatment selection while various treatment strategies are described in details in Chapters 4 through 13.

For distresses that are related to the existing pavement structure, pavement preservation treatments will not be appropriate; separate rehabilitation design(s) will need to be developed on a project basis. Nevertheless, the distress mechanisms described in the guide will still be useful for the development of the rehabilitation design. Tables 1-2 provides general guidelines for appropriate pavement preservation treatments of various types of distresses.

Table 1-2 General Treatment Guidelines for HMA Distress

CATEGORY	TYPE	DISTRESS SEVERITY LEVEL		
		LOW	MEDIUM	HIGH
Cracking	Longitudinal	Yes	No	No
	Fatigue	Yes	No	No
	Transverse	Yes	No	No
	Reflective	Yes	No	No
	Block	Yes	No	No
	Edge	Yes	No	No
Deformation	Rutting	Yes	No	No
	Corrugations	Yes	No	No
	Shoving	Yes	No	No
	Depression	Yes	No	No
	Overlay Bumps	Yes	No	No
Deterioration	Delamination	Yes	No	No
	Potholes	Yes	No	No
	Patching	Yes	No	No
	Raveling	Yes	No	No
	Stripping	No	No	No
	Polished Aggregate	Yes	No	No
	Pumping	No	No	No
Mat Problems	Segregation	Yes	No	No
	Checking	Yes	Yes	No
	Bleeding	Yes	No	No
Seals Coats	Rock Loss	Yes	Yes	Yes
	Segregation	Yes	Yes	Yes
	Bleeding / Fat Spots	Yes	Yes	No
	Delamination	Yes	No	No

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CHAPTER 2 MATERIALS

2.1 OVERVIEW

Materials play an important role in the efficient and effective use of maintenance treatments. Most materials used in maintenance treatments are covered in the Standard Specifications, SP's or SSP's that can be found on the Caltrans web site http://www.dot.ca.gov/hq/esc/oe/specs_html/index.html. Where the specifications are relevant, they are referenced in the specific treatment Chapters 4 through 13. This section discusses the main materials used and provides a general explanation of their composition, manufacturing, storage and handling techniques, and addresses special application requirements. In some cases, the materials themselves are derived from a mixture of raw materials. This section will also address some of these issues.

The two main materials comprising flexible pavement maintenance treatments are binder and aggregate. Asphalt binders in use in California include:

- Asphalt Binders
- Asphalt Emulsions (both conventional and polymer modified)
- Cutback Asphalts
- Polymer Modified Asphalts
- Asphalt Rubber

Aggregates in use in California cover a range of geological types. The general requirements, gradings, and physical properties are covered in various sections of the Standard Specifications (Caltrans, 1999a).

2.2 ASPHALT BINDERS

2.2.1 Paving Asphalt (Asphalt Cement) Constituent

Conventional paving asphalt is a complex hydrocarbon mixture which consists primarily of the residue from crude oil refining. The properties of the asphalt produced depend on its chemical composition, crude source and type, and the processing/refining method used (Kirk, 1978). Asphalt properties are highly temperature dependent. At temperatures above the softening point, i.e. when hot, asphalt liquefies and acts as a lubricant. At temperatures below the softening point, asphalt becomes semi-solid and acts like a glue. Below its freezing or brittle point, asphalt becomes brittle solid. Caltrans requirements for asphalt binders are described in Section 92 of the Standard Specifications.

2.2.2 Paving Asphalt Manufacture

Several processes are used to specifically manufacture asphalt including:

1. **Steam Distillation**: Steam distillation begins with the desalting and de-waxing of the crude oil. The crude is then heated to approximately 572°F (300°C) (Kirk, 1978). A furnace then heats the crude to 752°F (400°C) and the heated crude is continuously delivered to the flash zone of the atmospheric tower. The material is separated (by its boiling point) with the most volatile (lightest) components rising to the top and the less volatile escaping on the sides of the tower. The residue in the tower is stripped using steam to remove volatiles. For some heavy crudes, this residue may be suitable asphalt. In California, most asphalt cements used are steam distilled.

2. **Straight Run / Blending**: Vacuum tower residue may be suitable as paving asphalt or it may require blending with other feed stocks, fluxes from the vacuum tower, or from other parts of the process such as solvent de-asphalting.

3. **Solvent Refining**: Solvent refining of the asphalt rich fraction uses a short chain hydrocarbon (propane usually) to precipitate out the insoluble asphalt fractions.

4. **Air Blowing**: Air blowing has been used to harden asphalt to create higher viscosity grades. However, this has often led to asphalts with poor aging resistance and some agencies have not allowed asphalt processed in this manner. Light blowing is employed to modify feedstock of specific composition to create multi-grade asphalts of low thermal susceptibility.

2.2.3 Asphalt Specifications

Specifications drive production of asphalts that will perform well in the field. In the past, asphalt specifications were based on measurements of consistency at various temperatures which provided little information about expected performance. For many years, California operated under similar specifications for "Aged Residue" (AR) of asphalt which evolved to partial use of Performance based asphalts. In 2006, Caltrans adopted the Performance Graded (PG) system for asphalt binders, which is based on fundamental engineering properties of the asphalt over the entire range of expected service temperatures. In the PG system, the property requirements remain the same for all asphalt binders; what varies are the high and low temperature values at which these requirements are met.

In the PG system, asphalt is specified by:

- Dynamic Shear Rheometer (DSR) for performance at high and intermediate temperatures
- Bending Beam Rheometer (BBR) for performance at cold temperatures
- Aging Characteristics
- Purity and Safety

Table 2-1 lists the testing equipment and purposes in the PG grading system. Table 2-2 provides the specification for various PG grades, and the following paragraphs provide additional details.

1. **Dynamic Shear Rheometer (DSR):** is used to measure the properties of the asphalt binder at high and intermediate pavement service temperature. The asphalt binder is tested in the DSR in its original (unaged), oven aged (Rolling Thin Film Oven (RTFO) residue), and long term

aged conditions after conditioning by the pressure aging vessel (PAV). The original and RTFO- aged binders are tested at the maximum pavement design temperature to determine the asphalt susceptibility for rutting. PAV aged residue is tested at the intermediate design temperature to determine the asphalt binder's ability to resist fatigue cracking.

2. **Bending Beam Rheometer (BBR):** is used to test asphalt binder at low pavement service temperatures to determine the binder's resistance to thermal cracking. The BBR measures the stiffness S(t) and m-value. S(t) is a measure of the thermal stresses developed in the HMA as a result of thermal contraction. The slope of the stiffness curve, m, is a measure of the rate of stress relaxation.

3. **Aging Characteristics**: Aging in asphalt is associated with oxidation and hardening of the asphalt. During processing and while in service in the pavement, asphalt looses volatile fractions. The loss of this volatile material can lead to hardening. Aging is one cause of asphalt failure as the material becomes brittle, shrinks, and cracks. Short-term aging is simulated by exposure to air in a rolling thin film oven (RTFO) Long term aging during service life is simulated using a pressure aging vessel (AASHTO R-28).

   In the former aged residue (AR) specification, the properties of the asphalt are measured after aging protocols are performed. In California a rolling thin film oven test is used (California Test Method CT 374) to simulate the aging through the plant and paving operation.

4. **Purity and Safety**: Purity tests are based on the solubility of the asphalt in solvent, with trichloroethane, the most commonly used. Safety tests are based on the flammability or flash point of the fumes emitted by asphalt during heating. Caltrans uses the Cleveland Open Cup test to determine the flash point for asphalt binder material.

Table 2-1: Superpave Asphalt Binder Testing equipment and purposes (NCAT, 1996)

EQUIPMENT	PURPOSE	PERFORMANCE PARAMETER
Rolling Thin Film Oven, RTFO	Simulate binder aging during HMA production & construction	Resistance to aging during and immediately after construction
Pressure Aging Vessel, PAV	Simulate binder aging during HMA life	Resistance to aging over the length of pavement service life
Rotational Viscometer, RV	Measure binder properties at high construction temperature	Handling & pumping
Dynamic Shear Rheometer, DSR	Measure binder properties (stiffness and elasticity) at high and intermediate service temperatures	Resistance to permanent deformation (rutting) and fatigue cracking
Bending Beam Rheometer, BBR	Measure binder properties at low service temperatures	Resistance to thermal cracking

Table 2-2: Performance Graded (PG) Asphalt Grade Specifications (Caltrans, 2006)

PROPERTY	AASHTO TEST METHOD	SPECIFICATION GRADE				
		PG 58-22[a]	PG 64-10	PG 64-16	PG 64-28	PG 70-10
Original Binder						
Flash Point, Minimum °C	T48	230	230	230	230	230
Solubility, Minimum % [b]	T44	99	99	99	99	99
Viscosity at 135°C, [c] Maximum, Pa·s	T316	3.0	3.0	3.0	3.0	3.0
Dynamic Shear, Test Temp. at 10 rad/s, °C Minimum G*/sin(delta), kPa	T315	58 1.00	64 1.00	64 1.00	64 1.00	70 1.00
RTFO Test [e], Mass Loss, Maximum, %	T240	1.00	1.00	1.00	1.00	1.00
RTFO Test Aged Binder						
Dynamic Shear, Test Temp. at 10 rad/s, °C Minimum G*/sin(delta), kPa	T315	58 2.20	64 2.20	64 2.20	64 2.20	70 2.20
Ductility at 25°C Minimum, cm	T51	75	75	75	75	75
PAV [f] Aging, Temperature, °C	R28	100	100	100	100	110
RTFO Test and PAV Aged Binder						
Dynamic Shear, Test Temp. at 10 rad/s, °C Minimum G*sin(delta), kPa	T315	22 [d] 5000	31 [d] 5000	28 [d] 5000	22 [d] 5000	34 [d] 5000
Creep Stiffness, Test Temperature, °C Maximum S-value, MPa Minimum M-value	T313	-12 300 0.300	0 300 0.300	-6 300 0.300	-18 300 0.300	0 300 0.300

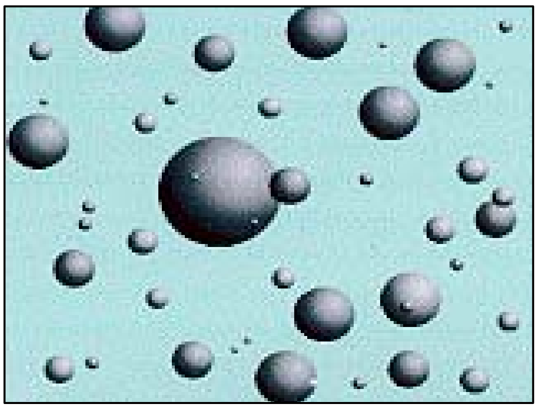
Notes:

a. For use as asphalt rubber base stock for high mountain and high desert area.
b. The Engineer will waive this specification if the supplier is a Quality Supplier as defined by the Department's "Certification Program for Suppliers of Asphalt."
c. The Engineer will waive this specification if the supplier certifies the asphalt binder can be adequately pumped and mixed at temperatures meeting applicable safety standards.
d. Test the sample at 3°C higher if it fails at the specified test temperature. G*sin(delta) shall remain 5000 kPa maximum.
e. "RTFO Test" means the asphaltic residue obtained using the Rolling Thin Film Oven Test, AASHTO Test Method T240 or ASTM Designation: D 2827. Residue from mass change determination may be used for other tests.
f. "PAV" means Pressurized Aging Vessel.

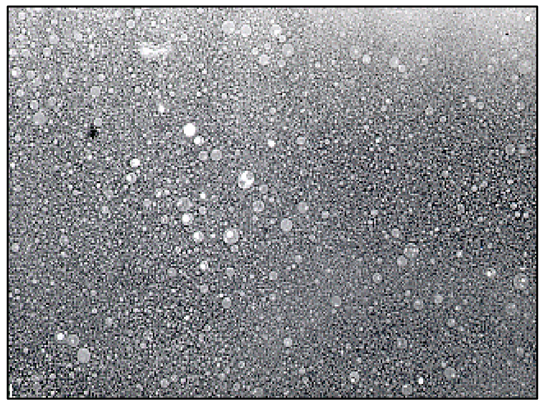
2.3 ASPHALT EMULSIONS

2.3.1 Emulsion Constituent

An emulsion is a dispersion of two or more liquids that will not mix together to form a single homogenous substance. An asphalt emulsion is asphalt dispersed in water. This is not a solution as the two phases (oil in water) are susceptible to separation. So, like a good salad dressing, the oil is stabilized with an emulsifier to keep it dispersed. Figure 2-1 shows an emulsion in schematic and an emulsion micrograph.



a) Emulsion Schematic



b) Emulsion Micrograph

Figure 2-1 Asphalt Emulsion Illustrations (Holleran, 1999)

In an emulsion, the particle sizes range from 3.94 x 10^{-5} to 3.94 x 10^{-3} inches (1 to 100 μm) in diameter. An emulsion lies between these two extremes and is defined by the size of the particles involved. This allows the particles (once chemically stabilized) to form a stable dispersion. When the particle size is less than one micron, the material is termed a colloid. Such systems may be stable without the use of extra chemical stabilizers as they are usually self-stabilizing (e.g., clay in water).

The process of separating the asphalt and water is called "breaking" (Holleran, 1999). The process by which the asphalt expels water and dries to an integral film or layer on the aggregate or surface is termed "curing" (Holleran, 1999). The mechanisms associated with breaking and curing are covered elsewhere.

Emulsions allow the formation of an asphalt binder with low enough viscosity for easy application. The dispersion in water gives the asphalt many of the properties of water such as low viscosity, lower temperature requirements for both application and storage, and less sensitivity to application on damp surfaces.

2.3.2 Emulsions Manufacture

Asphalt is semi-solid at ordinary temperatures 50 to 140°F (10 to 60°C). To make an emulsion, the asphalt must be sheared into small droplets and coated/reacted with a chemical stabilizer or emulsifier. Figure 2-2 shows the cross section of a typical colloid mill, one of the devices that is used to shear the asphalt. It should be noted that there are other methods of shearing the asphalt to produce an emulsion. These include homogenizers, pressure reducers and pumps. The colloid mill is the most commonly used to produce asphalt emulsions. The chemical emulsifier solution (also known as the soap solution) is combined with the asphalt and introduced into a gap between a high-speed rotor and a stator (or other rotor rotating at a lower speed). The resulting shear breaks the asphalt particles down to the required size. The geometry of the sheared particles has a big effect on the particle size distribution, which in turn affects the properties of the emulsion (Holleran, 2002).

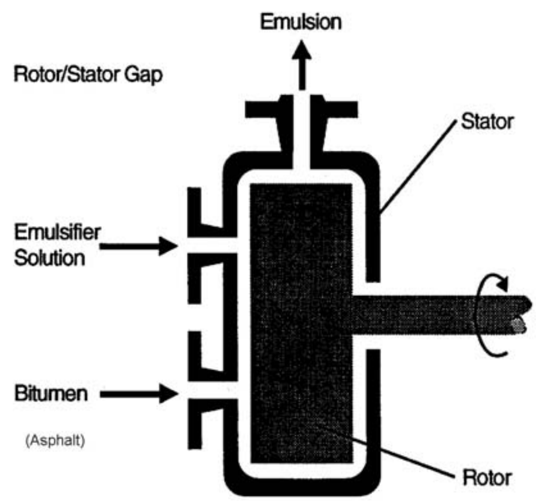


Figure 2-2 Colloid Mill Cross Section (Holleran, 1999)

In an emulsion plant several operations must be carried out. Figure 2-3 shows the key elements of an emulsion plant.

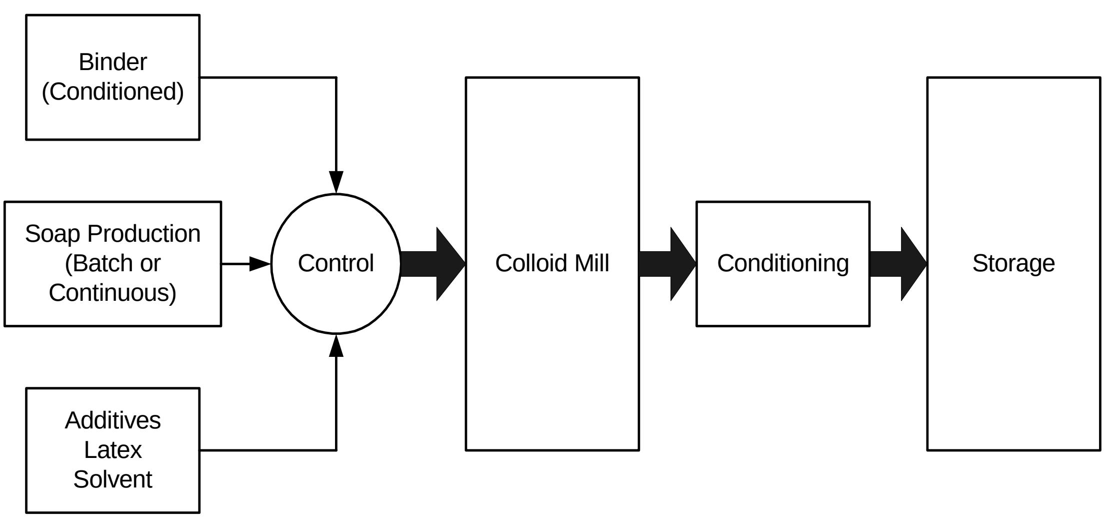


Figure 2-3 Emulsion Plant Operations Schematic (Holleran, 1996)

The asphalt must be stored correctly and at the right temperature. For normal operation (non polymer binder emulsification), the storage temperature will range from 275 to 284°F (135 to 140°C). For polymer-modified binders, the storage temperature will range from 320 to 338°F (160 to 170°C). If higher temperatures are required, the colloid mill must be operated under back pressure, about 29 to 43 psi (2 to 3 bar) and a heat exchanger on the mill outlet is required to ensure that the emulsion is cooled to below boiling temperatures before the back pressure is reduced to atmospheric pressure. If the backpressure and heat exchange operations are not properly carried out, the emulsion will boil and be destroyed.

The soap solution (emulsifier solution) preparation is required because the emulsifiers usually need to be reacted with a base or acid to create the surface-active or emulsifying form (salt). This may be done in a continuous fashion or in a batch fashion. As the reactions are between an acid and an alkaline emulsifier (cationic systems) or an alkaline chemical and an acid emulsifier (anionic systems), the pH of the soap solution and the pH of the resulting emulsion are key factors in the quality of the emulsion.

In many cases, additives for emulsion stability or modification are introduced. The most common method of modifying an emulsion is through the addition of rubber latex (synthetic or natural). The latex is either introduced via the soap solution or directly injected into the mill via the soap line. This method has the advantage that no heat exchanger or pressure operation is required.

2.3.3 Emulsifiers and Types of Emulsion

Emulsifiers in their neutralized state may have a negative charge (anionic), a positive charge (cationic), or no charge (nonionic) (Holleran, 1999). The exact chemistry and type of emulsifier determines the application of the finished emulsion. Other factors that determine physical and application characteristics include pH of the emulsion, the binder content, the particle size and distribution, and the compatibility with the aggregate sources. Anionic emulsifiers are based on fatty acids while cationic emulsifiers are based on various types of amines. Cationic emulsifiers are used for slow set, rapid, quick sets and micro surfacing of various types of amines depending on the application.

2.3.4 Anionic Emulsions versus Cationic Emulsions

Caltrans uses anionic and cationic emulsions for various applications. The choice between anionic and cationic is made based on the application requirements and the characteristics of the aggregate to be used in the mix. Generally, anionic emulsions of the slow set variety are more compatible with soils and easier to dilute with water. Thus, they are normally chosen for soil stabilization and fog seals. Anionic emulsions break by flocculation and coalescence. In this process, as water evaporates from the emulsion and the particles come into close contact, they stick together. These particles then "floc" or coalesce into larger particles. This process continues until the particles begin to form films and a reaction occurs (French Society, 2000). Thus, anionic emulsions are suitable for use with calcareous aggregates such as limestone, not typically used with setaceous.

Figure 2-4 illustrates material compatibility in general terms along with the associated breaking process. Cationic emulsions may be formulated for all application types and aggregates. These emulsions are most useful for rapid setting chip seals, slurry emulsions and microsurfacing emulsions. This is due to a cationic emulsion's specific reaction with all compatible aggregates that creates a stronger adhesive bond. For the same reason, cationic emulsions are also less susceptible to cooler conditions and dampness than anionic emulsions.

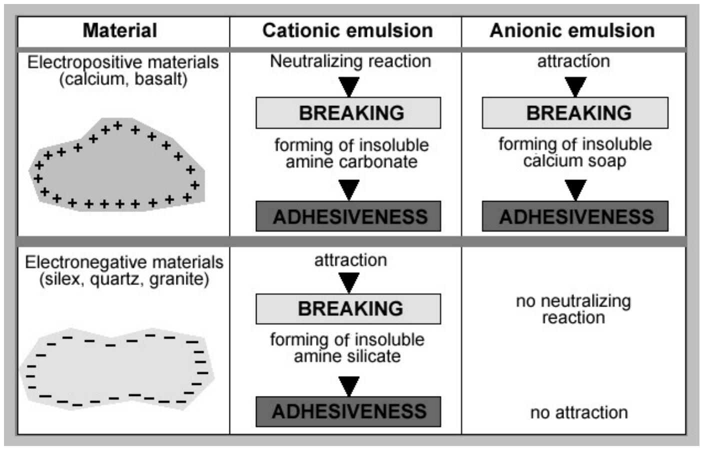


Figure 2-4 Material Compatibility and Reactivity of Emulsions (French Society, 2000)

The curing process is the same for both types of emulsion, except the reaction mechanism for cationic emulsion pushes water away from the aggregate surface. Thus, cationic emulsions tend to cure faster. The decreased curing time for cationic emulsions has implications in the application and handling of these emulsions. These implications will be discussed in the sections on specifications and storage and handling.

2.3.5 Specifications and Testing

1. **Caltrans Specifications**: Caltrans uses several common emulsion types. These are described in detail in Standard Specifications Section 94 (Caltrans, 1999a), and are briefly described below:

   - **Anionic Emulsions**: Rapid Set (RS), Medium Set (MS) and Slow Set (SS). There are subcategories that describe the base asphalt ("h" equals hard or 80/100-penetration grade or if there is no 'h" designation, it refers to the use of a softer grade- 120-150 pen grade). Numbers describe the binder content of the emulsion (1 for lower and 2 for the higher level). In anionic emulsions, these binder content designations are different for different grades; RS-1 is typically 55% minimum binder content, and RS-2 contains 65% minimum. Medium sets are 55 and 65% respectively and SS grades are only designated as SS-1 or SS-1h and are 57% minimum binder content.

   - **Cationic Emulsions**: Rapid set (CRS), Medium set (CMS) and Slow set (CSS). There are subcategories that describe the base asphalt ("h" equals hard or 80/100-penetration grade. If there is no 'h" designation, it refers to the use of a softer grade). Numbers describe the binder content of the emulsion (1 for lower and 2 for the higher level). In cationic emulsions, these binder content designations are different for different grades; CRS-1 is 60% minimum binder content, and CRS-2 65% minimum. Medium sets are 55 and 65% respectively and SS grades are only designated as CSS-1 or CSS-1h and are 57% minimum binder content.

   - **Polymer Modified Emulsions**: These may be anionic or cationic. They are all rapid set and have the letter P at the start of the designation. For example PMCRS-2h is a polymer modified cationic rapid set emulsion with the hard binder. All the emulsion binder contents for this class of emulsions are 65% minimum. These emulsion types are further discussed in Chapter 4 "Chip Seals".

- **Quickset Slurry Emulsions**: These may be anionic or cationic (QS or CQS) and have minimum binder contents of 57%. In general use are polymer modified (latex) versions of these emulsions and they have the letter "L" preceding the designation (e.g., LMCQS-1h). Such emulsions may be made with the hard binder or the softer binder. This is further discussed in Chapter 8 on Slurry Seals.

2. **What the Specifications Mean**: The test methods listed in the specifications (Caltrans, 1999a) are designed to provide an indication of the stability, physical characteristics, and performance of the emulsion. This section presents a general overview of tests contained in the specifications.

   - Binder content is measured by distillation or evaporation. This is important to know because application rates are based on residual binder.
   - Viscosity indicates the application properties (whether the emulsion can be pumped and sprayed) and whether it will remain where it is applied without running off. The viscosity of an emulsion is a function of the binder content within the emulsion, as illustrated in Figure 2-5. This figure indicates that as the binder content of the emulsion increases, so does its viscosity. Emulsions with higher viscosities are more difficult to pump and spray at a given temperature than are emulsions with lower viscosities.
   - Settlement and storage stability are determined by the same test, but performed over different periods of time. They determine if an emulsion can be stored without "breaking" in the storage container. If settlement occurs during the test (as shown in Figure 2-6), and is not re-dispersed, this is an indication that the emulsion may flocculate and coalesce ("break") during storage.
   - Demulsability is the measure of an emulsion's resistance to breaking and gives an idea of whether the emulsion is rapid or slow setting.
   - The coating test refers to mixing characteristics with soil or aggregate.
   - The cement-mixing test is a stability test that is relevant for mixing emulsions with soils or aggregates.
   - The sieve test provides an indication of foreign matter in the emulsion that might cause problems such as clogging nozzles during spraying or clogging in-line sieves during pumping operations. It is also an indication of stability. Figure 2-7 illustrates the Sieve Test.

Tests on residual binder are carried out to check the base asphalt and the polymer. Penetration and ductility are conducted on the residue of both conventional and polymer modified emulsions. Torsional recovery and infrared testing are used to examine polymer content. Torsional recovery is carried out using the equipment shown in Figure 2-8. The recovery from a torsional load is measured and related to polymer content (the test method used is CT 332).

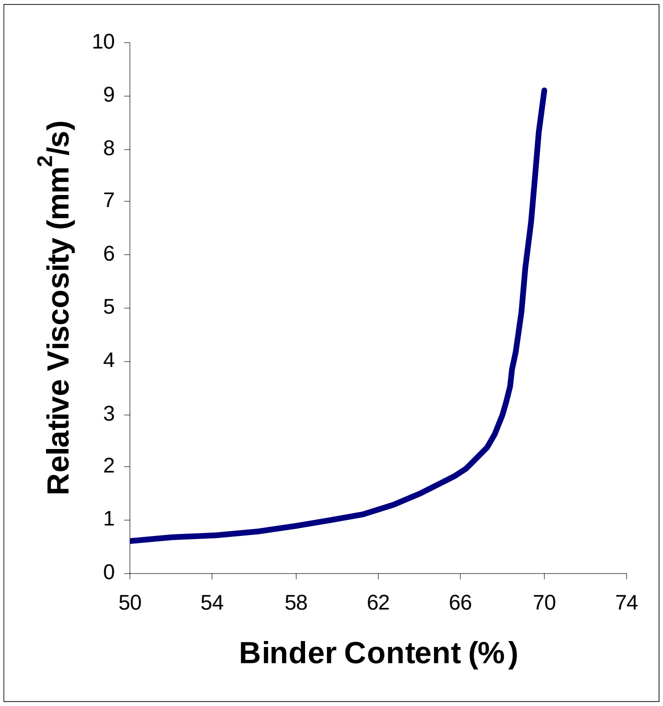


Figure 2-5 Relative Viscosity Vs Binder Content (Holleran, 2001)

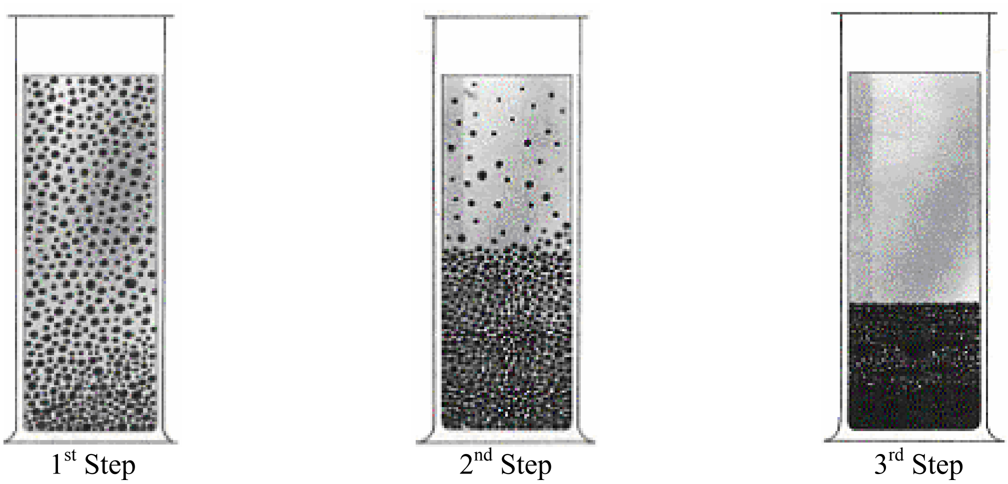


Figure 2-6 Settlement and Storage Stability Test (French Society, 2000)

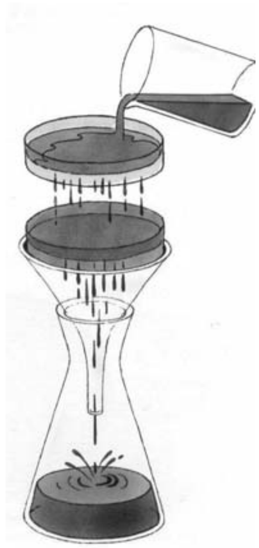


Figure 2-7 Sieve Test

(Note: Normally only 1 sieve is used in the AASHTO T-59 as used by CT) (French Society, 2000)

Figure 2-8 Torsional Recovery Test

2.4 CUTBACK ASPHALTS

2.4.1 Cutbacks Asphalts

A cutback is a solution of asphalt in a hydrocarbon solvent (e.g., kerosene, diesel, or naphtha). Solvents are used to reduce the asphalt's viscosity so that the cutback can be pumped and sprayed at lower temperatures (104 to 293°F [40 to 145ºC]) than that required for conventional asphalt. The solvent performs no other function in road applications. The solvent selected depends on the grade of the cutback, which in turn, is based on the expected setting rate.

During the 1970's energy crisis and in response to environmental concerns on volatile emissions (i.e., evaporation of the solvent during the application and curing processes), use of cutbacks has generally been discontinued. In California, only slow and medium cure cutbacks are still made and only slow cure cutbacks are generally specified. The main use for cutbacks is prime coats over aggregate base materials prior to placement of an asphalt-wearing course in new construction.

2.4.2 Manufacturing

Because cutbacks are solutions of asphalt and solvent, they are easily manufactured. This can be done on site by circulation in a tank. In refinery applications, inline blending or emulsion colloid mills have been used to manufacture cutbacks.

2.4.3 Specifications and Testing

The Caltrans cutback specifications are found in the Standard Specifications Section 93, and they are referred to as "Liquid Asphalts" (Caltrans, 1999a).

- Slow curing (SC): these contain a heavy oil solvent. Caltrans has four designations SC-70, SC-250, SC-800, and SC-3000. The number refers to kinematic viscosity of the cutback.

- Medium Cure (MC): these are made with a kerosene type solvent and have the same viscosity designations as SC grades.

The main specifications relate to safety as measured by flash point and water content, viscosity and boiling range of the solvent, application and cure rate, residue percentage for residual application rate, and residue tests to ensure the correct base asphalt grade had been used. The main effect of increasing the viscosity is to increase the application temperature requirements. This is covered in the Standard Specifications Section 93.

2.5 POLYMER MODIFIED BINDERS

2.5.1 Polymers and Polymer Modified Binders

Polymers are large molecules that are used to enhance the performances of asphalt cement and asphalt concrete pavement, particularly at high temperatures. Depending on the basic polymer units or monomers used, a wide range of properties can be achieved. For engineering purposes polymers are conveniently described as having glassy (stiffness) or rubbery (elastomeric) properties. Examples of polymers commonly used in asphalt mixtures include:

- Styrene Butadiene Copolymer (radial and linear) (SBS)
- Polyethylene (PE)
- Styrene Butadiene Rubber (SBR)
- Polybutadiene (PB)
- Ethylene Vinyl Acetate (EVA)
- Ehtylene Methyl Acrylate (EMA)
- Atactic Polypropylene (PP)
- Epoxies and Urethanes
- Tire Rubber (Crumb)

2.5.2 Polymer Modified Binder Manufacture

Many types of manufacturing configurations exist to make polymer-modified asphalts. Manufacturing may be done at high or low shear, on site, or in a factory. The main stages of manufacturing require the following procedures:

- Metering of Polymer, Asphalt, and Additives
- Wetting of the Polymer by the Asphalt/Additive Blend
- Dispersion of the Polymer
- Allowance for any Interaction (Reaction) of the Polymer with the Asphalt
- Storage and Transportation

Most of these are mechanical issues and are achieved by relatively simple techniques. Figure 2-9 illustrates a typical manufacturing (blending) plant.

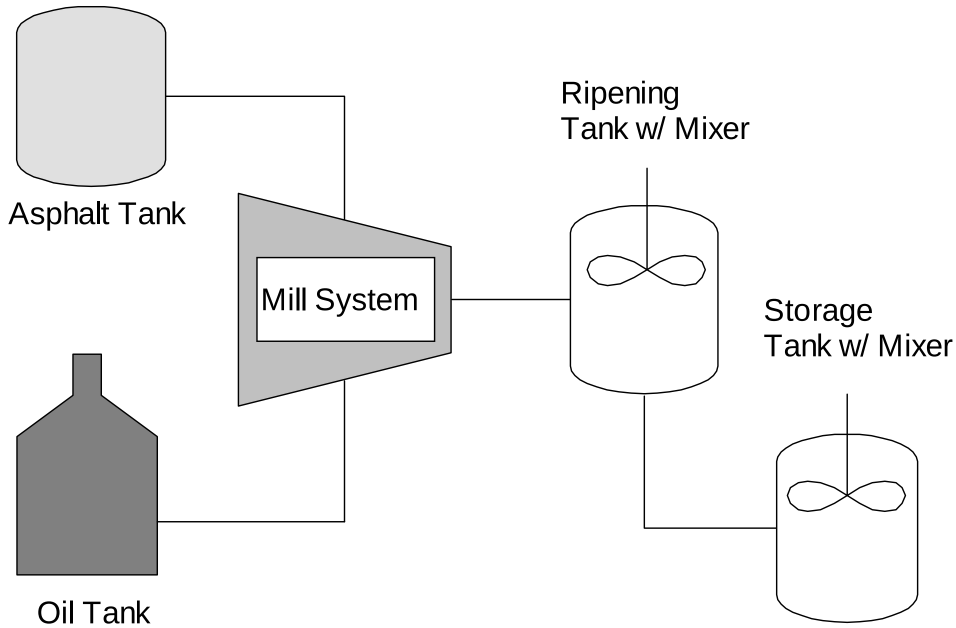
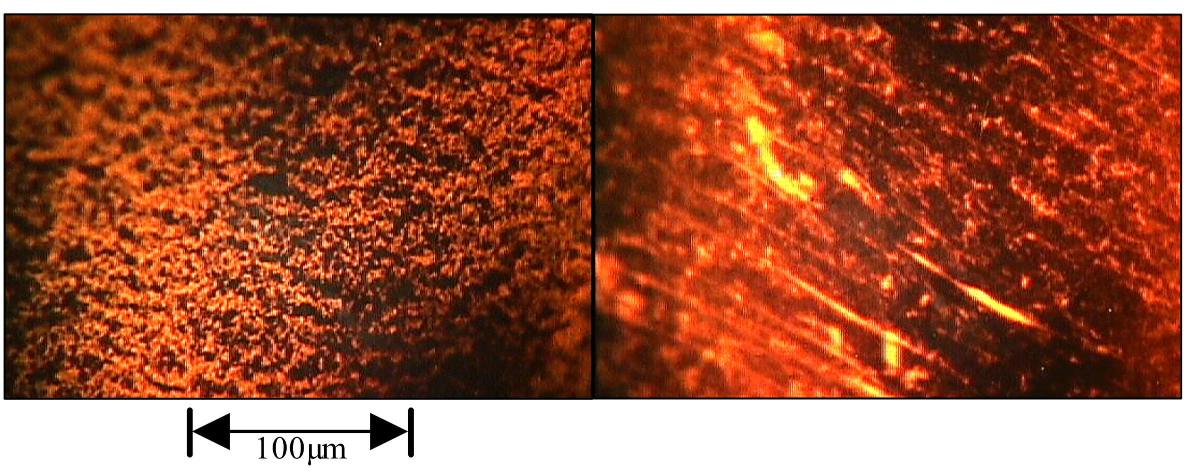


Figure 2-9 Typical Polymer Blending Plant (Holleran, 2001)

The most important steps in the manufacturing process are dispersion and reaction. This is what determines the structure (i.e., morphology) of the final binder and hence its properties. These steps also determine the level of polymer required to achieve the desired results. Compatible systems usually have superior rheological, aging, and stability properties to those of incompatible systems at the same polymer level (Holleran, 2001). The micrographs in Figure 2-10 show the structure (morphology) of SBS at 3% dispersion in a compatible (a) and incompatible (b) polymer system. The scale for both micrographs is the same.



(a) Compatible System

(b) Incompatible System

Figure 2-10 Micrographs of Polymer Systems (Holleran, 2001)

2.5.3 Polymer Modified Asphalts

Caltrans has adopted three specifications for polymer modified asphalt, PG58-34PM, PG64-28PM and PG76-22PM (Table 2-3). The different grades are suited for different climatic applications. The PM specification defines the performance characteristics of the binder. It also incorporates additional specifications for the elastic recovery and phase angle.

The polymer modified asphalts provide better high and low temperature properties than conventional grades and are used in areas with hot summers and cold winters. This is achieved through the use of SBS copolymers.

2.6 ASPHALT RUBBER

2.6.1 Asphalt Rubber Constituent

Scrap rubber, crumb rubber, and reclaimed rubber are all terms describing recycled rubber. The largest recycled rubber source is automobile and truck tires and is referred to as crumb rubber modifier (CRM). This rubber is not a pure polymer but a blend. Most car tires in the USA are made of mainly Styrene Butadiene Rubber (SBR) or polyisoprene and carbon black. Other polymers are included in some blends, and tires are not uniformly formulated or compounded. Truck tires generally contain a higher percentage of natural rubber than car tires (up to 30% of the combined polymer content).

The variations in the CRM may affect the properties. However, in asphalt rubber binders, the particle size of the added CRM is relatively large compared to a polymer modified system. Asphalt rubber binder is typically made in the field; that is, near to the job site for chip seal applications or at the hot plant site for hot mix applications.

The asphalt rubber specification is a recipe specification and is to some extent is detailed in the SSP's (Caltrans, 1999c). But, they must meet specific physical property requirements. Two rubber types are specified, one is tire rubber and the other is a high natural rubber recycled material. The required rubber properties are controlled by the SSP requirements (Caltrans, 1999c). Mixing temperatures are important and should be kept between 375 and 440°F (190 and 226°C). CRM Grading is important in determining the rate of digestion and the binder's final properties. These materials are mixed into asphalt that has been modified with extender oil (high aromatic hydrocarbon) at about 2% - 6% (Caltrans, 1999c).

The asphalt rubber binder improves fatigue life, resistance to rutting, and provides stone retention and crack alleviation in chip seals (Caltrans, 1999d) when compared to other binders. In California, asphalt rubber gap-graded overlays may be reduced up to 50% the thickness of conventional overlays and still provide the same resistance to reflective cracking, however half thickness does not apply to structural requirements. Caltrans uses asphalt rubber binders mainly in gap graded and open graded mixes. They are also used as SAM and SAMI seals as a reflection cracking treatment. Caltrans does not currently use asphalt rubber in dense graded mixtures.

Table 2-3 Performance Graded Modified Asphalt Binder (Caltrans, 2006)

PROPERTY	AASHTO TEST METHOD	SPECIFICATION GRADE		
		PG 58-34PM	PG 64-28PM	PG 76-22PM
Original Binder				
Flash Point, Minimum °C	T48	230	230	230
Solubility, Minimum % [b]	T44	99	99	99
Viscosity at 135°C, [c] Maximum, Pa·s	T316	3.0	3.0	3.0
Dynamic Shear, Test Temp. at 10 rad/s, °C Minimum G*/sin(delta), kPa	T315	58 1.00	64 1.00	76 1.00
RTFO Test [e], Mass Loss, Maximum, %	T240	0.6	0.6	0.6
RTFO Test Aged Binder				
Dynamic Shear, Test Temp. at 10 rad/s, °C Minimum G*/sin(delta), kPa	T315	58 2.20	64 2.20	76 2.20
Dynamic Shear, Test Temp. at 10 rad/s, °C Maximum (delta), %	T315	Note d 80	Note d 80	Note d 80
Elastic Recovery, Test Temp. Minimum recovery, %	T301	25 75	25 75	25 65
PAV [e] Aging, Temperature, °C	R28	100	100	110
RTFO Test and PAV Aged Binder				
Dynamic Shear, Test Temp. at 10 rad/s, °C Minimum G*sin(delta), kPa	T315	16 5000	22 5000	31 5000
Creep Stiffness, Test Temperature, °C Maximum S-value, MPa Minimum M-value	T313	-24 300 0.300	-18 300 0.300	-12 300 0.300

Notes:

a. Performance Graded Modified Asphalt Binder (PG Modified) will not be modified using acid modification.
b. The Engineer will waive this specification if the supplier is a Quality Supplier as defined by the Department's "Certification Program for Suppliers of Asphalt."
c. The Engineer will waive this specification if the supplier certifies the asphalt binder can be adequately pumped and mixed at temperatures meeting applicable safety standards.
d. Test temperature is the “temperature at which G*/sin(delta) equal 2.2 kPa”. A graph of log G*/sin(delta) plotted against temperature can be used to determine the test “temperature at which G*/sin(delta) is 2.2 kPa”. A graph of (delta) versus temperature can also be used to determine delta at “temperature where G*/sin(delta) is 2.2 kPa”. Direct measurement of (delta) at the “temperature at which G*/sin(delta) is 2.2 kPa” is also acceptable.
e. "PAV" means Pressurized Aging Vessel.

2.6.2 Asphalt Rubber Manufacture

To produce asphalt rubber binder, the asphalt cement is heated to approximately 375° to 440°F (190 to 226°C) at which time the CRM is added via a hopper system into a pre-wet tank. The asphalt contacts and wets the CRM particles. This mix is then transferred into a reaction vessel where it "reacts" with the lighter fractions in the asphalt oils that swell the outer areas of the particles. The asphalt and the rubber particles interact to form a gel coated particle (Caltrans, 1999d). This reaction is similar to the process of swelling that occurs in polymer asphalt systems (Caltrans, 1999b). The reaction is shown schematically in Figure 2-11.

How well this model reflects the actual situation and the relative effect of particle sizing is not clear but, based on polymer and asphalt chemistry, it seems adequate. It also explains why a significant change in properties occurs over time, since this type of system is not thermodynamically stable. Further, the increase in viscosity early in the interaction is due to the continuation of this solvation process (Holleran, 1998b) & (Australian Institute, 1993).

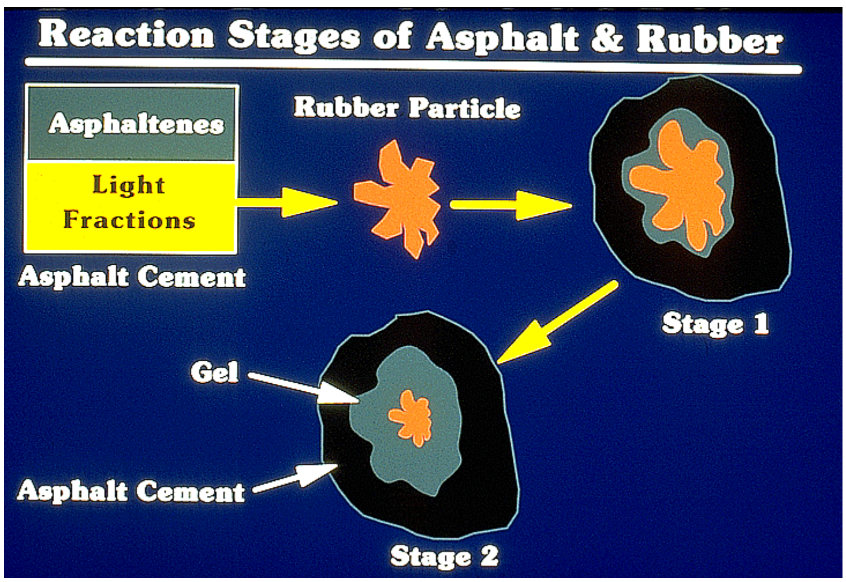
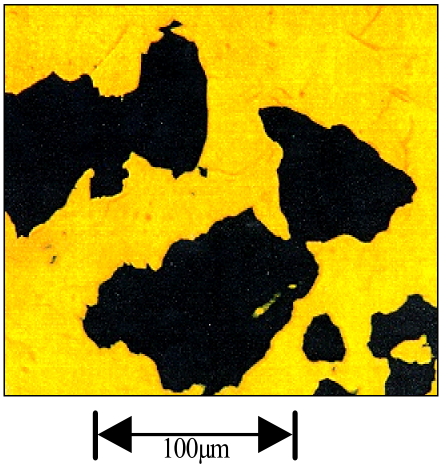


Figure 2-11 Asphalt Rubber "Reaction" (Caltrans, 1999d).

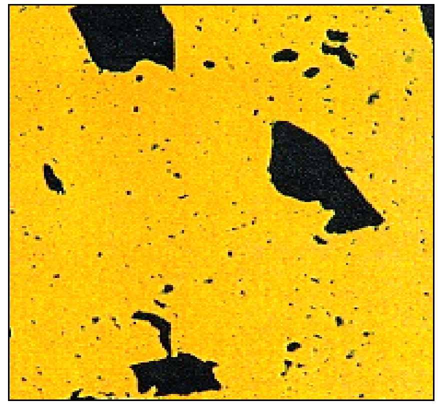
This can be shown by examining micrographs (see Figure 2-12) of asphalt rubber digested with and without extender oil (relative sizing is important; all micrographs are to the same scale and the largest particles are $3.94 \cdot 10^{-3}$ inches [100µm]). The amount of extender oil, interaction time and temperature affect digestion. However, the intent is not to achieve full digestion which causes viscosity to drop below acceptable limits for the binders.

2.6.3 Caltrans Specification Requirements for Asphalt Rubber

Caltrans SSPs for asphalt rubber binder (ARB) and rubberized asphalt concrete (RAC) mixes are currently being updated to reflect implementation of the performance graded (PG) asphalt binder system and will be incorporated into Section 39 of the Standard Specifications. The following discusses current SSP requirements and recommended changes developed by a Caltrans-Industry working group. For each project, a detailed review of the special provisions and other contract documents is recommended to assure compliance with the project requirements.



a) Without Extender Oil



b) With Extender Oil

Figure 2-12 Micrographs: Asphalt Rubber Extender Oil Effects (Holleran, 2001)

The Aged Residue (AR) system of asphalt binder grading is being replaced by the performance graded (PG) system. AR-4000 will no longer be specified as the base asphalt cement for asphalt rubber binders. Instead, PG 58-22 is specified as the base asphalt cement for use in asphalt rubber binders for the high mountain and high desert climate areas where resistance to cold temperature cracking is critical to long term performance. A stiffer grade, PG 64-16, is specified for use in asphalt rubber in the rest of California (coastal, valley, low or southern mountains, low desert). The change in grading systems should not present any major obstacles to asphalt rubber binder design. However, the base asphalt cement shall not be polymer-modified.

The current specifications for Asphalt Rubber Binder call for 20 ± 2 percent crumb rubber modifier (CRM) content by total binder mass. The CRM must include 25 ± 2 percent by mass of high natural rubber CRM and 75 ± 2 percent scrap tire CRM. No changes have been recommended to the types of CRM or relative proportions thereof. The scrap tire CRM consists primarily of No. 10 to No. 30 sized particles (2 mm to 600 µm sieve sizes). The high natural rubber CRM is somewhat finer, mostly No. 16 to No. 50 (1.18 mm to 300 µm sieve sizes).

The extender oil dosage for chip seals will remain at a range of 2.5 to 6 percent by mass of the asphalt cement. However, the minimum extender oil content for use in RAC mixes may be reduced to one percent to minimize potential for flushing and bleeding for hot climate, high traffic index (TI) locations.

Extender oils and high natural CRM are used to enhance the asphalt rubber interaction. Extender oils act as "compatibilizing" agents for the asphalt rubber interaction by supplying light fractions (aromatics, small molecules) that swell the rubber particles and help disperse them in the asphalt. High natural CRM has also been found to aid chip retention in chip seal applications, even at concentrations as low as 3 percent by asphalt rubber binder mass. Use of high natural CRM appears to improve the bond between cover aggregate and the asphalt rubber membrane.

It is important to understand that just mixing together proportions of arbitrarily selected asphalt, CRM and extender oil components within the specified ranges will not necessarily yield a binder that complies with the physical property requirements in the special provisions. Properties of asphalt rubber binders depend directly on the composition, compatibility and relative proportions of the component materials, as well as on the interaction temperature and duration. There are many combinations of suitable materials within the recipe proportions that simply do not provide an appropriate or even usable asphalt rubber binder. That is why binder design and testing procedures are essential to develop satisfactory asphalt rubber formulations.

2.7 AGGREGATES

2.7.1 Aggregate Properties

Aggregates are the major building material for pavements. The aggregate's role is to form the structural matrix in an asphalt concrete mix (hot or cold); which bears the traffic loads; as such their properties are critical to the success of a mix (Roberts, et. al, 1996). Local sources are generally used but some other materials such as expanded clay (light weight aggregate) or slag may be used if they meet the required specification. In areas where local materials are not suitable for use in the AC mixes, aggregate would have to be imported elsewhere. Major aggregate types that may be encountered in California include (Roberts, et. al, 1996):

- Igneous rocks: Volcanic rocks formed from molten rock. Examples are granite and basalt.
- Sedimentary rocks: Rocks formed by the laying down of layers of material that is then compressed. Examples include limestone, sandstone, and chert.
- Gravel: Formed from the breakdown of any natural rock. Usually found in rivers or waterways. River gravel is an example.
- Sands: These are formed from the deterioration of any natural rock. These often contain clay or silt and should be washed.
- Slag: This is a by-product of metallurgical processing. Slag can be from tin, steel, or copper processing. Slag is generally hard but absorbent (typically vesicular).

There are two major categories of aggregate properties of interest in pavement applications. These are the chemical and physical properties as discussed below:

Chemical Properties: Chemical properties of aggregates identify the changes an aggregate may go through due to chemical action. Some aggregates contain substances that are soluble in water, are subject to oxidation, hydration or carbonation. The main chemical property that affects asphalt applications, however, is affinity the aggregate has for the asphalt. Asphalt must wet the surface of the aggregate and adhere to it. Failure to do so may produce the phenomena of stripping and disintegration failure of the hot mix or loss of stone in other treatment types such as slurry or chip seal. No reliable indicators exist for determination of stripping potential based on chemistry of the aggregate alone and most tests are based on testing the mixture (AASHTO T283).

Physical Properties: The most important aggregate properties are listed below:

- **Grading or Particle Size Distribution**: Grading requirements are discussed in the chapters that deal with individual treatments. Caltrans specifies grading requirements for use in HMA in the Standard Specifications Section 39. The grading is important as it determines the mixture characteristics with respect to its physical properties. For example, in HMA this includes fatigue resistance and load bearing. In open graded asphalt concrete mixtures, it will determine porosity, while in chip seals and slurry surfacing it will determine seal durability. The individual grading requirements are further discussed in the chapters on treatments 4-13. CT 202 and CT 105 measure grading. The latter test method is used if there is a difference in specific gravity of 0.2 or more between the coarse and fine portions of the aggregate or between blends of different aggregates.

- **Cleanliness or Presence of Deleterious Materials:** Dirty aggregates may cause adhesion problems in chip seal and HMA and cohesion problems in slurry surfacing. Lumps of clay may disintegrate under freeze thaw conditions or cause pockmarks in a HMA pavement. Specific testing and requirements are discussed in the chapters concerned with treatments. The Sand Equivalent test (CT 217) is used to measure this property for HMA aggregates.

- **Hardness or Abrasion Resistance:** Aggregates transmit the wheel loads to the subgrade. They must be resistant to crushing and wear to maintain this function. They must also resist crushing and degradation during stockpiling. A polished or worn aggregate will reduce skid resistance. The LA abrasion test (CT 211) is used to measure hardness and abrasion resistance.

- **Durability or Soundness:** Aggregates must be resistant to break down due to the cyclic action of wetting and drying and freeze and thaw cycles. CT 214 can be used to determine soundness.

- **Particle Shape and Surface Texture:** Aggregate particles for use in most treatments should be cubical rather than flat or elongated. This creates more interlock and internal friction in generating higher deformation resistance. In chip seals, it creates greater seal texture depth and skid resistance. The surface texture and the shape are a determinant to workability in mixes and may affect compaction. A rough fractured particle has a higher surface area and forms tougher adhesive bonds. Caltrans measures only fractured faces (CT 205).

- **Absorption Characteristics:** Most aggregates absorb asphalt to some extent; reducing the effective volumetric percentage of the binder mixtures or the effective application rate in chip seals. These changes can result in raveling of the pavement. Caltrans uses the Centrifuge Kerosene Equivalent and the Oil Ratio Test (CT 303) test to measure the absorption of aggregate.

Special aggregate requirements for specific treatments are considered in the relevant chapters.

2.7.2 Aggregate Manufacture

Aggregates are manufactured in quarry operations by first blasting (if necessary) and then using a series of crushers and screens to create the desired stone sizes. Several methods of crushing may be used; which include jaw crushers (usually the primary crusher), impact crushers (these produce cubical aggregates and are generally used later in the process), attrition mills, hammer mills and gyratory cone crushers. The combination must be chosen to meet the required specifications. Aggregates may also be mixed from gravel deposits.

2.8 STORAGE AND HANDLING

The key aspects of storing and handling any product include safety and quality. It is essential to ensure safety in handling at all times and to maintain quality so that the material remains in specification from manufacture to the intended end use.

This section covers storage and handling of:

- Conventional Asphalt
- Modified Asphalts (including asphalt rubber, polymer modified, and MBs)
- Asphalt Emulsions
- Aggregates

2.8.1 Asphalt Binders

When handled properly, asphalts may be reheated or maintained at elevated temperatures without adverse effects. If asphalt is thermally abused in storage, handling or application, it may harden and compromise service properties.

Avoiding Problems during Storage

The main methods of avoiding potential storage problems are to ensure that equipment is properly designed, in good working condition and correct procedures are established and followed. All asphalt tanks should be designed and built in accordance with a recognized standard (e.g., API 650). General design considerations include tank shape, tank foundations, tank thickness, and tank access. Best management practices require a secondary containment around all tanks. Vertical tanks yield the highest asphalt to tank volume ratio of all tank configurations. Vertical tanks with a cone shaped roof are preferred, although temporary storage in horizontal tanks is acceptable. The operational tank design considerations relate to:

- **Minimizing the risk of overheating**: The tank requires accurate thermal sensors. They should be positioned in the region of the heaters and also uniformly distributed throughout the tank. The probes should be in thermal wells and removable for cleaning and calibration. Heating may be accomplished via heat transfer (oil or steam), electric coils, or direct fired. As asphalt is a good insulator (i.e. not a good conductor of heat), the heating rate must be controlled to prevent localized overheating, particularly when direct-fired systems are used. The heating rate should be limited to 77°F (25°C) per hour (Asphalt Institute MS-22, 1998).

- **Minimizing oxidation and loss of volatiles**: In order to minimize oxidation and loss of volatiles, contact with air must be minimized. This may be accomplished by designing pressure-tested, fully enclosed tanks. To avoid air entrainment, all circulation lines should re-enter the tank under the liquid level. When filling a tank, it should be filled from the bottom and the asphalt should not be allowed to freefall as this can result in entrapped air. Venting is an essential safety precaution and cannot be eliminated to reduce oxidation.

- **Maintaining asphalt homogeneity**: To maintain asphalt homogeneity and avoid temperature variation, the asphalt should be mixed on an intermittent basis. This may be done through circulation or through the use of side mixers under the liquid level. Vortex mixing entrains air and its use should be avoided. When adding fresh asphalt to a tank, circulation is necessary to stabilize temperature and combine the existing material with the fresh material.

- **Minimizing heat loss**: To conserve energy, all tanks should be insulated with fiberglass or rock wool insulation. This insulation should be at least 2 in (50 mm) thick and sheathed in aluminum or galvanized steel at least 0.03 in (0.7mm) thick. Additionally, lines should be insulated and heat traced with electric tape, steam or oil.

Safety hazards can arise from:

- **High Temperatures**: Since asphalt must be stored at high temperatures, safety issues involving burns, along with the material's contact with water, which causes rapid expansion resulting in foaming and explosive boil over, must be addressed. Burns may be avoided by always using the correct safety apparel. Additionally, ensure that all lines and surfaces are thoroughly insulated.

  Due to the potentially hazardous side effects of water contacting high temperature asphalt, steps need to be taken to avoid this interaction. As water is slightly lighter than asphalt, it will move to the top of tanks. However, during transport cold water may migrate to the bottom of a tank. Water entrapment in tanks can be avoided by using watertight cone topped tanks, ensuring that tanks are watertight and hatches are sealed. Water finding gel should be used to check tanks before filling. If water is present, the asphalt should be heated through the range from 198 to 257°F (92 to 125°C) at a rate of 18 to 27°F (10 to 15°C) per hour. Silicone antifoaming agent at 0.1 % can also be added. Pipes and any additives that are to be blended with the asphalt need to be checked for water.

- **Flammable or explosive atmospheres**: Asphalts normally have flash points exceeding 482°F (250°C). However, flammable atmospheres may form if contamination by light products (e.g., products created from cleaning or flushing lines) is disturbed. Ignition sources may include sparks, or static electricity. With this in mind, proper grounding is important along with the use of shielded electric motors.

- **Presence of toxic materials**: Fumes can be generated when asphalt is heated. These fumes contain particulate asphalt, hydrocarbon vapor, and sulfide gases. The latter is highly toxic and tends to build up in headspace. Proper venting is required to dispose of these fumes.

Recommended Storage and Handling Temperatures and Times

Asphalt and modified asphalt are stored and handled in similar ways. An exception is asphalt rubber, which is used shortly after manufacture. Allowable storage times are product specific and take into account the rate of property change, which occurs during storage. For example, a conventional asphalt can be stored for several months, and asphalt rubber is typically formulated overnight (holdovers).

2.8.2 Asphalt Emulsions

Asphalt emulsions are a convenient way of handling asphalt but emulsions may be subject to settlement or breaking prematurely. For this reason storage and handling are important issues. Over time emulsions will become coarser and undergo property changes, to avoid these problems timely use is often required. There are some simple rules for storage and handling of asphalt emulsions and they are discussed below.

Handling

Handling of emulsions is not difficult. By following the rules below potential problems can be avoided.

- **Pumping**: Pumps are a way of doing work on an emulsion. Pumps usually compress or shear the material they pump. This results in a compressed emulsion. If compression is too severe or occurs too often, the emulsion will become coarser by the mechanism of flocculation and coalescence and may revert back to straight asphalt. Pumps should be selected carefully. Diaphragm pumps are gentle, but require high maintenance and should only be used if essential. Centrifugal pumps are acceptable as long as the peripheral speed is not too high, less than 300 rpm. Positive displacement pumps may be used, but usually 2-3 thousandths of an inch must be shimmed from the gears to provide adequate clearance and lastly old and worn pumps may be used. Always get expert advice on the appropriate pump to use.

- **Temperature**: When asphalt materials get cold, they shrink. In an emulsion, this means that the asphalt droplets get closer together. This has a number of important consequences. The material can flocculate and may coalesce; this may also cause the emulsion to settle out faster than desirable. If the material is pumped when cold the droplets are more compressed due to temperature related shrinkage. As a result, a pump that was not too tight in January may be far too tight in July. If the emulsion actually freezes, the droplets become frozen in contact and the emulsion will revert to bitumen upon thawing. For most emulsions, this happens if the emulsion gets to below 40°F (4°C). When materials get hot they expand. However, when water gets hot, its evaporation rate increases enormously. If the water evaporates, the droplets get closer together and can result in an emulsion reverting back to asphalt by the action of flocculation and coalescence. If any part of the emulsion gets hotter than 203°F (95ºC) localized boiling may occur. If this happens, the droplets fuse back into asphalt. This fusing process raises a number of important aspects surrounding the heating process including the following:

    - When heating emulsions do it gently and heat according to specifications.
    - Use agitation while heating.
    - Warm pumps before use.
    - On bulk tanks in cold areas, the use of electrical heating is recommended.
    - Do not apply direct heat to emulsions with fire or a blowtorch.

Transport Handling

Emulsions are generally stable enough to transport. However, a common problem arises when air enters the emulsion. Air can cause the emulsion to break in the bubbles of air; CRS emulsions are particularly prone to break in this way. These larger particles can "seed" the emulsion causing settlement. Problems also arise when transport tanks are not clean. Mixing cationic and anionic emulsions can lead to breaking of the emulsion.

Storage

The points made for storing asphalt relate equally to the storage of an emulsion. When an emulsion is stored, it has a finite lifetime. This lifetime is determined by the formulation, handling and storage of the emulsion.

Asphalt is slightly heavier than water and as a result asphalt particles move to the bottom of the storage container. This movement is referred to as settling. If the particles pack in this way they can stick together (flocculate and coalesce) if this continues the emulsion will eventually turn back into bitumen. This settlement may be controlled to some extent by formulation. If the emulsion particles are fine enough to start with, they will settle more slowly allowing for longer storage life. Flocculation and coalescence can also occur as the result of electrical attraction between particles. If an emulsion is electrically unstable, it will flocculate and coalesce. This process may not take the emulsion entirely back to bitumen but the large particles formed as a result of this process will settle faster.

It is important to prevent settling by mixing an emulsion prior to the start of flocculation or coalescence. Once an emulsion has coarsened, remixing will not separate the larger particles again. If it has coarsened too much, pumping may break the emulsion. The only way to prevent problems is to start with a very fine emulsion and keep it properly maintained.

Tankage

While vertical tanks are preferred for plant storage, mobile storage is done with a road tanker. The road tanker increases the surface area of the emulsion exposed to air and can promote skinning. However, if properly handled, this will not become an issue for fieldwork. Table 2-4 shows the storage and application temperatures for emulsions currently in use by Caltrans (METS, 2002; Asphalt Institute MS-4, 1989; Holleran, 1998a).
Specific guides for tankage include:

- Bulk tanks should be circulated at regular intervals. Circulation should be done slowly.
- The frequency of circulation will depend on the weather and how long the emulsion has spent in storage.
- Most emulsions only require circulation once a week in summer and once every five days during the winter.
- Circulation should be performed in the middle of the day, not first thing in the morning due to the colder temperatures.
- The time of circulation is based on the size of the tank; a 1320 gal (5000 L) tank should be circulated for 15 minutes while a 2640 gal (10,000 L) tank requires 20 minutes.
- Pumps must be flushed after use, but never into the emulsion tank.
- Lines and pumps should be able to be warmed before use.
- Lines should not be left part full of emulsion.

Cleaning Procedures

For emulsions, cleanliness is very important. A sloppy operation will produce problems. When an emulsion comes in contact with air, it can begin to break. When a cationic emulsion comes into contact with metal, it can begin to break. Thus, if a pump is not properly cleaned after use, it will clog. If lines are left part full of emulsion, they will clog. The higher the performance of the emulsion, the more critical cleaning is. Cleaning should be done before storage of equipment and it should be done thoroughly. Specific guidelines include:

- Flush equipment including hoses thoroughly with WATER.
- Flush equipment and hoses with kerosene, NOT diesel, distillate or other solvent. These materials may dissolve asphalt but they are also incompatible with the emulsion and may cause the emulsion to break rather than flush it away. *NEVER FLUSH INTO THE EMULSION TANK.*
- Finish with a second flush with water.
- If a pump or line is already clogged with bitumen gentle heat may be applied at the blockage. Do not apply heat to the lines, as this will break the emulsion.
- Soak pumps with kerosene for an hour or more.
- Flush again with water after blockage is removed.

Table 2-4 Mixing, Spraying and Storage Temperatures of Emulsions

PRODUCT	MIXING TEMPERATURE °F (°C)	SPRAYING TEMPERATURE °F (°C)	STORAGE TEMPERATURE °F (°C)
RS-1	N/A	68-140 (20-60)	68-140 (20-60)
RS-2	N/A	68-140 (20-60)	122-185 (50-85)
MS-1	50-158 (10-70)	68-158 (20-70)	68-140 (20-60)
MS-2	50-158 (10-70)	N/A	122-185 (50-85)
MS-2h	50-158 (10-70)	N/A	122-185 (50-85)
SS-1	50-158 (10-70)	50-140 (10-60)	50-140 (10-60)
SS-1h	50-158 (10-70)	50-140 (10-60)	50-140 (10-60)
CRS-1	N/A	68-140 (20-60)	50-140 (10-60)
CRS-2	N/A	122-185 (50-85)	122-185 (50-85)
CMS-2s	50-158 (10-70)	N/A	122-185 (50-85)
CMS-2	50-158 (10-70)	N/A	122-185 (50-85)
CMS-2h	50-158 (10-70)	N/A	122-185 (50-85)
CSS-1	50-158 (10-70)	68-140 (20-60)	50-140 (10-60)
CSS-1h	50-158 (10-70)	68-140 (20-60)	50-140 (10-60)
PMRS-2	N/A	122-185 (50-85)	122-185 (50-85)
PMRS-2h	N/A	122-185 (50-85)	122-185 (50-85)
PMCRS-2	N/A	122-185 (50-85)	122-185 (50-85)
PMCRS-2h	N/A	122-185 (50-85)	122-185 (50-85)
QS-1	50-104 (10-40)	N/A	50-140 (10-60)
QS-1h	50-104 (10-40)	N/A	50-140 (10-60)
CQS-1	50-104 (10-40)	N/A	50-140 (10-60)
CQS-1h	50-104 (10-40)	N/A	50-140 (10-60)
LMCQS-1h	50-104 (10-40)	N/A	50-140 (10-60)
MSE	50-104 (10-40)	N/A	50-140 (10-60)

Rust, dirt, grass or other foreign material should be kept out of the emulsion. This is especially important when working with cationic emulsions as they can break by reacting with foreign materials.

The main transport requirements are to ensure that correct pumping is used, pumps should be warmed in cool climates. Clean tanks or a switch-load process should be followed. Switch loading is a process by which materials are transported in tanks that last carried a compatible material and therefore do not require the tank to be cleaned between material switching.

Table 2-5 provides acceptable switch loading combinations. Always pump into clean tanks and always transport full containers. Emulsions are chemical systems. In order to avoid contamination, they should never be mixed with other types of emulsions or with other chemicals.

Table 2-5 Acceptable Switch Load Combinations (Asphalt Institute MS-4, 1989)

LAST PRODUCT IN TANK	PRODUCT TO BE LOADED			
	ASPHALT CEMENT	CUTBACK ASPHALT	CATIONIC EMULSION	ANIONIC EMULSION
Asphalt Cement	OK to Load	OK to Load	Empty to No Measurable Quantity	Empty to No Measurable Quantity
Cutback Asphalt	Empty to No Measurable Quantity	OK to Load	Empty to No Measurable Quantity	Empty to No Measurable Quantity
Cationic Emulsion	Empty to No Measurable Quantity	Empty to No Measurable Quantity	OK to Load	Empty to No Measurable Quantity
Anionic Emulsion	Empty to No Measurable Quantity	Empty to No Measurable Quantity	Empty to No Measurable Quantity	OK to Load
Crude Petroleum and Residual Fuel Oils	Empty to No Measurable Quantity	Empty to No Measurable Quantity	Empty to No Measurable Quantity	Empty to No Measurable Quantity
Any Product Not Listed Above	Tank Must be Cleaned	Tank Must be Cleaned	Tank Must be Cleaned	Tank Must be Cleaned

2.8.3 Aggregates

Aggregates must be handled and stored in a manner that avoids contamination, minimizes degradation and avoids contamination (Asphalt Institute MS-22, 1998). Specific guidelines are as follows:

- Stockpile areas should be clean and stable to avoid contamination from the surrounding area.
- Stockpiles should be on free draining grades to avoid moisture entrapment.
- Stockpiles should be separated for different aggregate sizes to prevent inter-mingling.
- Segregation or separation of a blended aggregate is the primary concern. Segregation occurs mostly with coarse aggregates but even slurry-combined aggregate may segregate in the stockpile or on handling if it gets too dry. Segregation may be avoided by avoiding stockpiling in a cone shape. Acceptable stockpile shapes are either horizontal or radial. Making each end dump load a separate pile, each adjacent to the next, makes horizontal stockpiles. Radial stockpiles are made with a radial stacker (Asphalt Institute MS-22, 1998).
- Degradation of the aggregate creating fines can be avoided by handling the stockpile as little as possible. In chip seal or slurry surfacing applications, re-screening may be considered.

2.9 SAMPLING REQUIREMENTS

The following is the standard sampling requirements for testing. In the case of emulsions, sampling is a significant issue. Samples must be sent immediately for testing to ensure they are representative of the material used in the field.

Emulsions, as has been discussed, change and coarsen with storage and handling. This may result in an emulsion that is out of specification when tested despite being in specification when sampled and used. This is especially true of high binder PMCRS-2 and 2h type materials.

2.9.1 Sampling Guidelines

The following guidelines should be followed for sampling materials **(**Asphalt Institute MS-22, 1998):

- Samples of emulsion and binder shall be taken in conformance with the requirements in AASHTO T 40, “Sampling Bituminous Materials,” and Section 8-01 and 8-02 of the Construction Manual and California Test Method 125.
- Observe safety procedures.
- Sample binders daily using new, clean, dry 0.26 gal (1 L) cans with screw lids.
- Samples are normally taken from the application lance at the rear of the distributor. Drain off sufficient material through the nozzle to ensure removal of any material lodged there.
- Samples should be taken after one-third and not more than two-thirds of the load has been removed.
- Do not submerge sample containers in solvent or wipe containers with solvent saturated cloths. Use a clean, dry cloth, only immediately after sampling, to clean containers.
- Attach a Sample Identification Form (TL-0101) to each material sample in accordance with Section 8-01 of the Construction Manual and instructions printed on the TL-0101 booklet.
- Protect the TL-0101 against moisture and stains.
- Provide the e-mail address of the Resident Engineer on the TL-0101.
- Emulsions have a shelf life. It is important that all samples be sent to the Transportation Laboratory daily.
- Aggregates should be sampled according to the contractual requirements.
- Samples of aggregate shall be taken according to Section 39-3.03 “Proportioning” of the Standard Specifications.
- Samples may be taken from a conveyor belt or sampling chute.
- Field samples must be taken from the stockpile. AASHTO T 2 and Section 39 3.03 of the Standard Specifications (Caltrans, 1999a) describe the method.

2.9.2 Sample Delivery

Samples for testing should be delivered to the Transportation Laboratory:

Division of Materials Engineering and Testing Services
Flexible Pavement Materials Branch, MS #5
5900 Folsom Boulevard
Sacramento, California 95819-4612

The following should be noted:

- Samples are not to be shipped C.O.D.
- Emulsion will be tested for compliance with Section 94, “Asphaltic Emulsions”, of the Standard Specifications (Caltrans, 1999a).
- Aggregate samples should be tested for compliance with Section 39 “Asphalt Concrete” or Section 37 “Seal Coats” of the Standard Specifications (Caltrans, 1999a) as appropriate.
- Test results are mailed to Resident Engineers. To expedite return of test results, test cards can be e-mailed to the Resident Engineers, if an e-mail address is provided on the TL-0101.

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CHAPTER 3 FRAMEWORK FOR TREATMENT SELECTION

3.1 GENERAL CONSIDERATIONS

There are many factors that are considered in the process of selecting an appropriate treatment for a pavement. These include pavement age, condition, traffic levels, expected future plans, as well as available funding and agency policy. At the network level, a general relationship exists between pavement condition and pavement age. For a properly constructed new pavement, the only treatments that are required are preventive maintenance (maintenance performed to delay the onset of distress). Then, as the pavement ages, it may become a candidate for routine maintenance (crack sealing or chip sealing), rehabilitation and eventually reconstruction. The purpose of this chapter is to provide guidance on treatment strategy selection. Figure 3-1 illustrates the treatment strategies employed based on the condition index of the existing pavement.

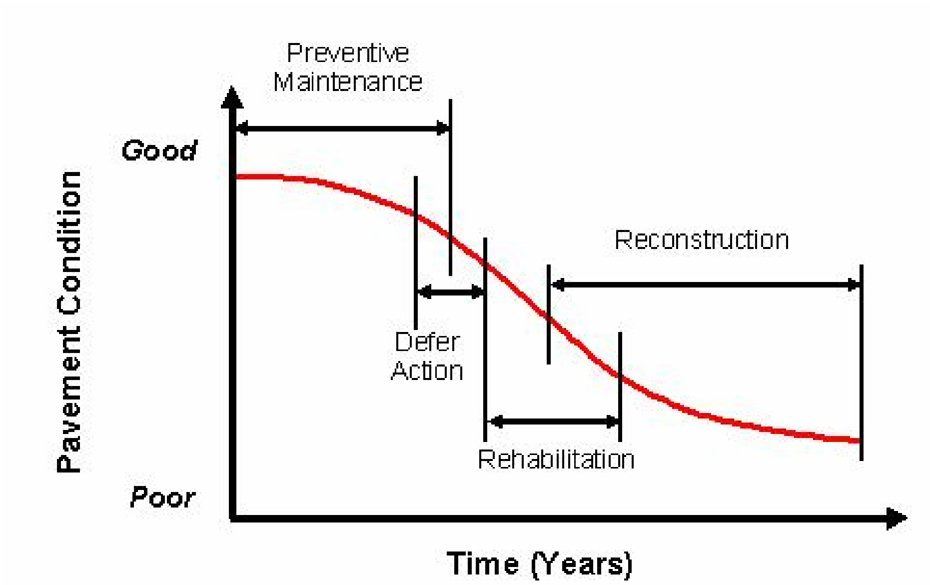

Figure 3-1 Treatment Strategy Based on Pavement Condition

Once an appropriate maintenance strategy has been chosen, a specific treatment is selected to address the specific distress mechanism for the pavement. The most important factors to consider when choosing a maintenance treatment include:

- Will the treatment address the distresses present? (i.e., Will it work?)
- Can the required preparation for the treatment be carried out?
- Is the treatment cost effective?
- Will the treatment be performed before the situation being addressed changes?

3.2 SELECTION PROCESS

There are three basic steps in the maintenance treatment selection process. These steps include:

- Assess the existing conditions.
- Determine the feasible treatment options.
- Analyze and compare the feasible options with each other.

3.2.1 Assess the Existing Conditions

The first step of the treatment selection process is to perform an evaluation of the existing conditions. This evaluation can be broken down into three processes, which include:

- Visual site inspection and/or inspection of project information from a database and/or records.
- Testing the existing pavement, as conditions require.
- Define the performance requirements for the treatment.

The Caltrans Field Distress Manual (Caltrans, 2002) or Caltrans Pavement Survey (Caltrans, 2000) may be used to identify pavement distress mechanisms. Treatment methods for the distress mechanisms are discussed in the following chapters of this document.

It is helpful to assess pavements using a pavement assessment form of some kind. A well-developed form promotes uniformity in the assessment process. The District Maintenance Engineer or other reviewer should fill out the pavement assessment form, on site, for each pavement being considered for treatment. Figure 3-2 illustrates an example of a pavement assessment form (Caltrans, 2002) and the type of information that should be collected.

3.2.2 Determine the Feasible Treatment Options

Once the pavement condition has been quantified, test results collected and analyzed, and other available data are reviewed, feasible treatments can be identified. In this context, "feasibility" is determined by a treatment's ability to address the functional and structural condition of the pavement while also meeting any future needs. Note that feasibility is not a function of affordability, because at this stage of the selection process the primary purpose is to determine what treatments might work. Figure 3-3 illustrates the Caltrans matrix for treatment options and Figure 3-4 shows Caltrans general guidelines for effective maintenance treatments on cracks.

Distress Survey Date: ____________________ Air Temperature : Before: _____ After: _____

Surveyor: ____________________ Pavement Surface Temp: Before: _____ After: _____

Station PM/KP	Cracking																		Deformation				
	Longitudinal, a			Fatigue, b			Transverse, c			Reflective, c			Block, b			Edge, a			Rutting, d	Corrugation, b	Shoving, e	Depression, b	Overlay Bumps, c
	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H					

a = Length, meter; b = Area, square meter; c = Number and length, meter; d = Maximum depth, mm. Record plastic flow (Yes/No); e = Number and square meter
L = Low severity; M = Moderate severity; H = High severity

Figure 3-2 Typical Pavement Rating Form – Visual (Caltrans, 2002)

Preventive Treatments				Rutting		Climate				Traffic Volumes										Treatment Costs				
																				Cost: $/SQ YD (Treatment Only)				
	Raveling	Oxidation	Bleeding	<1/2"	>1/2"	Desert	Valley	Coastal	Mountains	adt < 5000	adt>5000<30,000	adt >30,000	Night	Cold	Stop Points	urban	Rural	High Snow Plow use	Cost per lane-mile (Total Project Cost includes traffic control)	Large Projects	Medium Projects	Small Projects	Addtl Premium for night work $/SQ YD	Addtl Premium for Short Work Periods or Work Zones $/SQ YD
Crack/Joint Seal																								
Emulsion	N	N	N	N	N	G	G	G	G	G	G	G	N	N	G	G	G	G	8,000	0.50-0.65	0.60-0.75	0.70-0.85	+0.15-0.20	+0.60-1.00
Modified (Rubber)	N	N	N	N	N	G	G	G	G	G	G	G	G	G	G	G	G	G	8,000	0.55-0.70	0.65-0.80	0.75-0.90	+0.15-0.20	+0.60-1.00
Seal Coats																								
Fog Seal (See note 1)	F	G	N	N	N	G	G	G	G	F	F	N	N	P	F	G	G	F	13,000	0.15-0.30	0.15-0.30	0.15-0.30	+0.05	+0.10
Rejuvenator (See note 1)	G	G	N	N	N	G	G	G	G	G	F	N	N	N	N	G	G	F	15,000	0.20-0.50	0.20-0.50	0.20-0.50	+0.10	+0.20
Scrub Seal (See Note 4)	G	G	N	N	N	G	G	G	G	G	F	N	N	G	N	F	G	P	17,000	2.15	2.15	2.15	N/A	N/A
Slurry Seals																								
Type II (See note 1)	F	G	N	N	N	G	G	G	F	G	G	G	N	N	G	G	G	P	23,000	1.60-2.20	1.75-2.40	1.90-2.60	N/A	+0.30
Type III	G	G	N	F	N	G	G	G	F	G	G	G	N	N	G	G	G	P	24,000	1.60-2.20	1.75-2.40	1.90-2.60	N/A	+0.30
REAS	G	G	N	F	N	G	G	G	F	G	G	G	N	N	G	G	G	P		1.20-1.80	1.20-1.80	1.20-1.80	N/A	+0.30
Microsurfacing																								
Type II	G	G	N	G	F	G	G	G	G	G	G	G	G	N	G	G	G	P	31,000	2.00-2.80	2.10-2.90	2.25-3.00	+0.10-0.20	N/A
Type III	G	G	N	G	G	G	G	G	G	G	G	G	G	N	G	G	G	P	31,000	2.00-2.80	2.10-2.90	2.25-3.00	+0.10-0.20	N/A
Chip Seals																								
PME - Med. Fine (See Note 4)	G	G	N	F	N	G	G	F	F	G	G	N	N	N	P	P	G	P	27,000	1.80-2.00	2.25-2.75	3.00-3.50	N/A	+0.50-1.00
PME - Medium (See Note 4)	G	G	N	F	N	G	G	F	F	G	N	N	N	N	P	P	G	F	27,000	1.80-2.00	2.25-2.75	3.00-3.50	N/A	+0.50-1.00
PMA - Medium (See Note 3.)	G	G	N	F	N	G	G	G	G	G	G	N	N	G	P	P	G	F	24,000				N/A	
PMA - Coarse (See Note 3.)	G	G	N	F	N	G	G	G	G	G	N	N	N	G	P	P	G	G	24,000				N/A	
AR - Medium	G	G	N	F	N	G	G	G	G	G	G	N	G	G	P	P	G	F	65,000	3.75-4.55	4.00-4.75	4.25-5.00	N/A	+0.50-1.00
AR - Coarse	G	G	N	F	N	G	G	G	G	G	N	N	G	G	P	P	G	G	65,000	3.75-4.55	4.00-4.75	4.25-5.00	N/A	+0.50-1.00
Cape Seals																								
Slurry	G	G	N	F	N	G	G	G	G	G	G	G	N	N	G	G	G	P						
Micro	G	G	N	G	F	G	G	G	G	G	G	G	N	N	G	G	G	P						
PM Alternative to a Seal Coat > 30,000 ADT																								
PBA-O	G	G	P	F	N	G	G	G	G	G	G	G	F	F	G	G	G	P	65,000	8-12	8-14	10-16		+1.20-4.00
RAC-O	G	G	P	F	N	G	G	G	G	G	G	G	F	P	G	G	G	P	60,000	10-14	10-14			+1.50-3.50
RAC-O High Binder (HB)	G	G	P	F	N	G	G	G	G	G	G	G	F	P	G	G	G	P	65,000	10-14	10-14			+1.50-3.50
RAC-G	G	G	P	G	F	G	G	G	G	G	G	G	F	F	G	G	G	G	65,000	10-14	10-14			+1.50-3.50
PBA-G	G	G	P	P	N	G	G	G	G	G	G	G	F	F	G	G	G	G	60,000	8-12	8-14	10-16		+1.20-4.00
Thin Bonded Wearing Course (BWC)	G	G	P	F	N	G	G	G	G	G	G	G	F	F	G	G	G	G	85,000	10-14	10-14			+1.50-3.50
Thin Bonded Wearing Course Rubber (BWC-RAC O/G)	G	G	P	F	N	G	G	G	G	G	G	G	F	F	G	G	G	G	85,000	10-14	10-14			+1.50-3.50
Maintenance Treatments																								
Thin Lifts Overlays																								
Conventional	G	G	P	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	45,000	8-12	8-14	10-16		+1.20-4.00
PBA	G	G	P	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	60,000	8-12	8-14	10-16		+1.20-4.00
RAC	G	G	P	G	F	G	G	G	G	G	G	G	F	F	G	G	G	G	65,000	10-14	10-14			+1.50-3.50
Digouts	P	P	G	N	G	G	G	G	G	G	G	G	G	G	G	G	G	G	125,000					

Last revised 03/22/07

G-Good Performance F - Fair Performance P - Poor Performance N - Not Recommended

Note: 1. Usually limited to shoulders, low volume roads and parking areas.

Note: 2. Generally used on shoulders, parking areas and locations where less aggressive surface is desired.

Note: 3. Under evaluation. Please consider other strategy at this time.

Note: 4. Use of Pass Rejuvenating Seal Under evaluation. Please consider other PME strategy at this time.

Figure 3-3 Caltrans Maintenance Treatment Matrix

	Type of Cracking														
	Alligator "A"			Alligator "B"			Alligator "C"			Longitudinal/Transverse			Edge		
Criteria	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Width / Area	<1/4" or <10%	>1/4", <1/2" or >10%, <20%	>1/2" or >20%, <30%	<1/4" or <10%	>1/4", <1/2" or >10%, <20%	>1/2" or >20%, <30%	<1/4" or <10%	>1/4", <1/2" or >10%, <20%	>1/2" or >20%, <30%	<1/4"	>1/4", <1/2"	>1/2"	No Material Loss	>0%, <10% Material Loss	>10% Material Loss
Preventive Treatment															
Crack/Joint Seal (See Note 5)															
Emulsion	N	F	N	N	P	N	N	N	N	**G**	F	N	G	P	P
Modified (Rubber)	N	G	P	N	P	N	N	P	N	P	G	F	P	P	P
Seal Coats															
Fog Seal (See note 1)	G	P	N	G	N	N	F	N	N	F	N	N	F	P	P
Rejuvenator (See note 1)	G	N	N	G	N	N	F	N	N	F/	N	N	F	P	P
Scrub Seals	G	F	N	G	F (See Note 4)	N	G	F (See Note 4)	N	P	N	N	F	P	P
Slurry Seals															
Type II (See note 1)	F	N	N	F	N	N	F	N	N	F	N	N	F	P	P
Type III	F	P	N	F	P	N	F	P	N	F	P	N	F	P	P
Microsurfacing															
Type II (See note 2)	G	N	N	F	P	N	F	P	N	F	N	N	P	P	P
Type III	G	P	N	F	P	N	F	P	N	F	N	N	P	P	P
Chip Seal															
PME - Med. Fine	G	P	N	G	F (See Note 4)	N	G	P (See Note 4)	N	P	P	N	P	P	P
PME - Medium	G	P	N	G	F (See Note 4)	N	G	P (See Note 4)	N	P	P	N	P	P	P
PMA - Medium (See Note 3.)	G	P	P	G	F (See Note 4)	P	G	P (See Note 4)	P	P	P	N	P	P	P
PMA - Coarse (See Note 3.)	G	P	P	G	F (See Note 4)	P	G	P (See Note 4)	P	P	P	N	P	P	P
AR - Medium	G	G	F	G	G	F	G	F (See Note 4)	F	P	F	F	P	P	P
AR - Coarse	G	G	F	G	G	F	G	F (See Note 4)	F	P	F	F	P	P	P
PM Alternative > 30,000 ADT															
Con ventional															
PBA OGAC	G	F	N	G	F (See Note 4)	N	G	F (See Note 4)	N	G	F	P	P	P	P
RAC-O	G	G	F	G	G	F (See Note 4)	G	G	F	G	F	P	P	P	P
RAC-O High Binder (HB)	G	G	F	G	G	F (See Note 4)	G	G	F	G	F	P	F	F	F
RAC-G	G	G	G	G	G	F (See Note 4)	G	G	G	G	F	P	G	G	G
Thin Bonded Wearing Course Rubber (BWCR)	G	G	G	G	F (See Note 4)	F (See Note 4)	G	F (See Note 4)	F	F	F	P	P	P	P
Maintenance Treatments															
Conventional	G	G	F	G	G (See Note 4)	P (See Note 4)	G	G	F	P	F	F	N	F	F
PBA	G	G	G	G	G (See Note 4)	P (See Note 4)	G	G	G	P	F	F	N	F	F
RAC	G	G	P	G	P (See Note 4)	P	G	F	P	P	P	F	N	F	F
BWC	G	G	G	G	F (See Note 4)	F (See Note 4)	G	F (See Note 4)	F	F	F	P	P	P	P
Digouts	N	N	F	N	N	G	N	N	G	N	F	F	N	F	G

Last revised 7/01/06

G-Good Performance F-Fair Performance P - Poor Performance N - Not Recommended

Note: 1. Usually limited to shoulders, low volume roads and parking areas.

Note: 2. Generally used on shoulders, parking areas and locations where less aggressive surface is desired.

Note: 3. Under evaluation. Please consider other strategy at this time.

Note: 4. Effective when proper Prep Work has been performed.

Note: 5. Per Maintenance Manual, Cracks <1/4 inch - Crack Seal Not Recommended.

Figure 3-4 Caltrans General Guidelines for Effective Maintenance Treatments on Cracks

Once the feasible options have been determined, the limitations of each of the options should be taken into account in relation to its suitability vs. the other feasible options. Treatment limitations are imposed by such factors as deflection, pavement, curvature, roughness and permeability. The most inexpensive option that satisfies the maintenance requirements within its limitations should be considered first. At this point, a life cycle analysis or other cost effectiveness measure should be made as discussed in the next section.

3.2.3 Analyse and Compare the Feasible Treatment Options

It is likely that there will be several treatments that are identified as feasible. In comparing these different treatments, thought should be given to the treatment placement cost, the life of the treatment and whether or not the treatment extends the life of the pavement. Additional factors to consider when analyzing and comparing treatment options are: the cost effectiveness, traffic level, construction limitations, and any factors, such as weather, curing times or local issues that affect a specific treatment. The most desirable treatment is the one that provides the greatest benefit (whether that benefit is measured in terms of improvement in condition, extension of pavement life, or even, more simply, the life of the treatment) for the lowest life cycle costs. At this point a life cycle or other cost effectiveness measure should be made.

Reconstruction and maintenance costs rise as a pavement ages. However, if maintenance and/ or rehabilitation (M&R) is carried out too early the costs are prohibitively high. There is an optimum time at which maintenance can be performed to provide the maximum cost effectiveness. Figure 3-4 shows a typical cost effectiveness relationship with respect to timing of treatment applications.

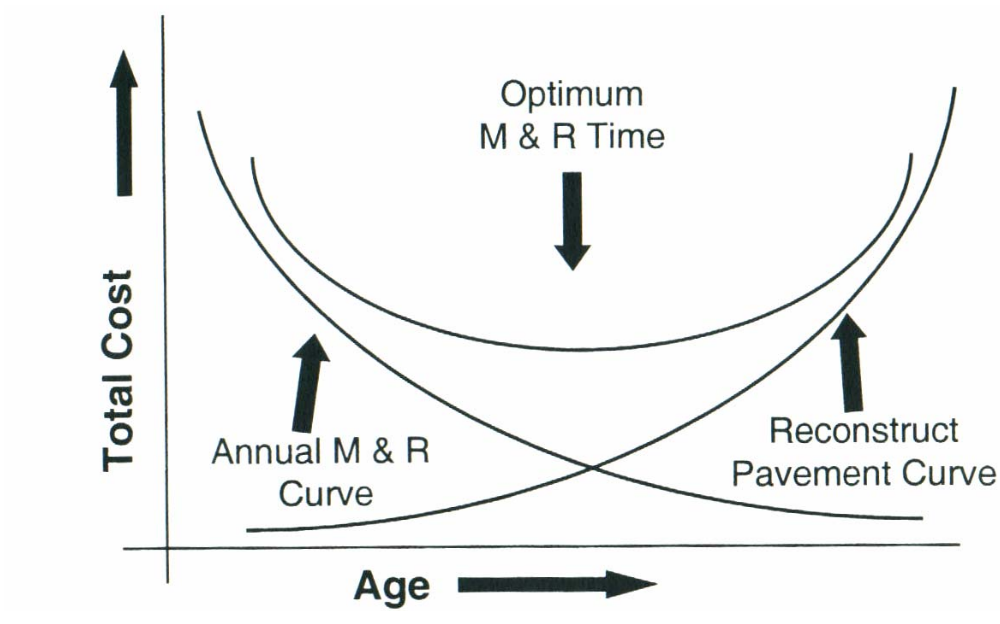

Figure 3-5 Treatment Timing versus Costs (Hicks, 1998)

Cost Effectiveness

Caltrans calculates cost effectiveness using the Caltrans Pavement Condition Report (Caltrans, 2000) system. However, for an initial assessment a more simplified approach may be employed (Hicks, 2000). This simplified approach is useful as costs and actual bid prices fluctuate. One simplified approach that can be used is the equivalent annual cost (EAC). In this method an equivalent annual cost is calculated using the following equation (Hicks, 2005):

EAC = Unit Cost of Treatment / Expected Life of Treatment…………………….. (3.1)

At this stage the treatment that meets the performance requirements with the lowest EAC may be selected. Other, more complex, methods exist (O'Brien, 1989) and may be used to calculate whole of life costing.

Choosing from the Maintenance Treatment Matrix

The main issues to consider when selecting between accepted treatments listed in the Caltrans treatment selection matrix are:

- Performance and Constructability
- Customer Satisfaction

Performance and constructability factors include the expected life of a treatment, seasonal effects on a treatment, existing pavement conditions, the existing pavement structure and the EAC calculated for the treatment. The contractor's experience, materials availability and weather limitations should also be taken into account. Each of these items is rated on a scale of 1 to 5. The District Maintenance Engineer or local supervisor should assign the ratings based on their individual experience. The ratings are based on the fact that a treatment is suitable when it is properly applied; however, project limitations such as climate conditions and material limitations may prohibit proper procedures from being followed. In situations where new products or material sources are being introduced, a risk factor should be considered, and a lower rating given to these materials. Similarly, if a contractor is unfamiliar with the new product or new material a lower rating should be given, despite the technical properties of a new product.

Customer satisfaction factors are social factors and include: traffic disruption, skid resistance achieved and noise level. Aesthetic factors such as dust and general appearance are also included. This allows a feasible option to be evaluated on factors other than cost and performance. The most cost effective and long lasting treatment may not be the right treatment for the right pavement at the right time under some conditions.

The rating factor is the weight, based on overall importance to the job success, assigned to a specific treatment's attribute; the higher the rating the more significant the attribute's impact on the job's success. The sum of all rating factors must equal 1.0. Figure 3-5 illustrates a blank ratings evaluation worksheet while Figure 3-6 shows an example of a worksheet comparing a chip seal and a microsurfacing for a particular job. Based on the results of the worksheet (Figure 3-6), a microsurfacing treatment (Total Score of 3.55) would be chosen over the chip seal (Total Score of 2.90) for this job. This process should be repeated for all potential treatments that meet the feasibility requirements.

RATING FACTOR		SCORING FACTOR CHIP	SCORING FACTOR MICRO		RATING FACTOR		TOTAL SCORE CHIP	TOTAL SCORE MICRO
PERFORMANCE EVALUATION ATTRIBUTES								
%	Expected Life			×		=		
%	Seasonal Effects			×		=		
%	Pavement Structure Influence			×		=		
%	Influence of Existing Pavement Condition			×		=		
CONSTRUCTABILITY ATTRIBUTES								
%	Cost Effectiveness (EAC)			×		=		
%	Availability of Quality Contractors			×		=		
%	Availability of Quality Materials			×		=		
%	Weather Limits			×		=		
CUSTOMER SATISFACTION ATTRIBUTES								
%	Traffic Disruption			×		=		
%	Noise			×		=		
%	Surface Friction			×		=		
100 %					***Total***			

RATING FACTOR: PERCENT OF IMPACT ON TREATMENT DECISION (total must = 100%)
SCORING FACTOR: 5 = Very important
4 = Important
3 = Some importance
2 = Little importance
1 = Not important

Figure 3-6 Rating Evaluation Work Sheet (Hicks, 1998)

NOTE: Ratings may vary from one district to another.

RATING FACTOR		SCORING FACTOR CHIP	SCORING FACTOR MICRO		RATING FACTOR		TOTAL SCORE CHIP	TOTAL SCORE MICRO
PERFORMANCE EVALUATION ATTRIBUTES								
15 %	Expected Life	**3**	**4**	×	**0.15**	=	**0.45**	**0.60**
10 %	Seasonal Effects	**2**	**3**	×	**0.10**	=	**0.20**	**0.30**
5 %	Pavement Structure Influence	**3**	**3**	×	**0.05**	=	**0.15**	**0.15**
5 %	Influence of Existing Pavement Condition	**4**	**2**	×	**0.05**	=	**0.20**	**0.10**
CONSTRUCTABILITY ATTRIBUTES								
10 %	Cost Effectiveness (EAC)	**5**	**4**	×	**0.10**	=	**0.50**	**0.40**
5 %	Availability of Quality Contractors	**4**	**3**	×	**0.05**	=	**0.20**	**0.15**
10 %	Availability of Quality Materials	**3**	**2**	×	**0.10**	=	**0.30**	**0.20**
5 %	Weather Limits	**3**	**4**	×	**0.05**	=	**0.15**	**0.20**
CUSTOMER SATISFACTION ATTRIBUTES								
20 %	Traffic Disruption	**1**	**5**	×	**0.20**	=	**0.20**	**1.00**
5 %	Noise	**1**	**4**	×	**0.05**	=	**0.05**	**0.15**
10 %	Surface Friction	**5**	**3**	×	**0.10**	=	**0.50**	**0.30**
100 %					***Total***		***2.90***	***3.55***

RATING FACTOR: PERCENT OF IMPACT ON TREATMENT DECISION (total must = 100%)
SCORING FACTOR: 5 = Very important
4 = Important
3 = Some importance
2 = Little importance
1 = Not important

Figure 3-7 Example Ratings Evaluation Worksheet
Chip Seal Vs. Microsurfacing (Hicks, 1998)

3.3 REFERENCES

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CHAPTER 4 CRACK TREATMENT

4.1 OVERVIEW

Cracking in pavements occurs when a stress is built up in a layer that exceeds the tensile or shear strength of the pavement materials. Crack sealing and crack filling are methods used to repair cracks in pavement surfaces. The cause of the crack and its activity play a dominant role in determining the success of crack sealing or filling operations. This chapter addresses crack treatment techniques associated with flexible hot mix asphalt (HMA) pavements.

Cracking may be associated with various distress mechanisms. Cracks provide paths for surface water to infiltrate the pavement structure and cause damage. Crack types include: fatigue cracks, longitudinal cracks, transverse cracks, block cracks, reflective cracks, edge cracks, and slippage cracks (Caltrans, 2000a). Each crack type is discussed below:

Fatigue Cracking: These cracks are also referred to as alligator cracks as they present in a pattern similar to an alligator's skin as illustrated in Figure 4-1. They are the result of repetitive traffic loads or high deflections often due to weak and/or wet bases or subgrades. This type of cracking is structural and, if not repaired, typically develops into potholes and pavement disintegration. Neither crack sealing or filling can treat this type of structural failure. Longitudinal cracking in the wheel paths is often the first visible sign that alligator cracking is starting to develop. Caltrans refers to longitudinal cracking in the wheel path as Alligator A and multiple interconnected cracks in the wheel path as Alligator B cracking. Alligator C cracking is multiple interconnected cracking across the entire roadway.

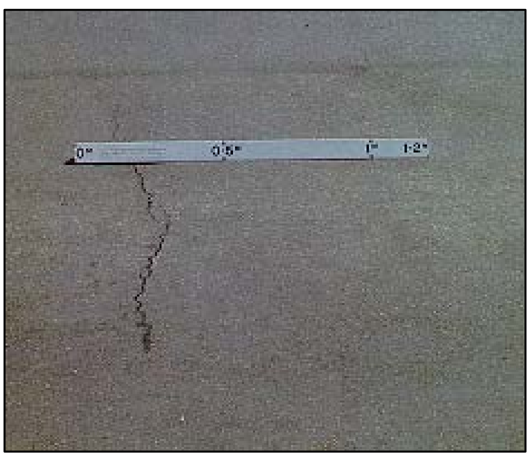
Longitudinal Cracks: These cracks run longitudinally along the pavement, as shown in Figure 4-2, and are caused by thermal stress and/or traffic loadings. They occur frequently at joints between adjacent travel lanes or between a travel lane and the shoulder, where hot mix density is lower and voids are higher. Longitudinal cracking may be associated with raveling and poor adhesion or stripping. These cracks can be effectively treated with crack sealants.

Figure 4-1 Fatigue Cracking

Figure 4-2 Longitudinal Cracking

Transverse Cracks: These cracks occur perpendicular to the centerline of the pavement, or laydown direction, as shown in Figure 4-3. Transverse cracks are generally caused by thermally induced shrinkage at low temperatures. When the tensile stress due to shrinkage exceeds the tensile strength of the HMA pavement surface, cracks occur. Thermal cracks often penetrate through the entire layer and typically widen over time. These cracks can be effectively treated with crack sealants, but deep cracks need to be filled first to avoid excessive application of crack sealant.

Block Cracking: These cracks form regular blocks (Figure 4-4) and are the result of age hardening of the asphalt coupled with shrinkage during cold weather. They can be effectively treated with crack sealants.



(Direction of Travel →)
Figure 4-3 Transverse Cracking

Figure 4-4 Block Cracking

Reflection Cracking: Reflection cracks are caused by cracks, or other discontinuities, in an underlying pavement surface that propagate up through an overlay due to movement or differential stresses across the crack. They exhibit any of the crack patterns mentioned and must be treated according to the original distress mechanism. Figure 4-5 illustrates reflection cracking in asphalt concrete over a jointed portland cement concrete pavement.

Edge Cracking: These are crescent-shaped or fairly continuous cracks that intersect the unbound pavement edge and are located within 2 ft (0.6 m) of the pavement edge, adjacent to an unpaved shoulder. They include longitudinal cracks outside of the wheel path and within 2 ft (0.6 m) of the pavement edge (SHRP, 1993). Figure 4-6 illustrates edge cracking. Edge cracks are caused by overloading at the unbound edge of the pavement, shear failure, or erosion (loss of support) in the shoulder. This structural type of cracking cannot always be effectively treated with crack sealants.

Slippage Cracks: These cracks produce a characteristic crescent shape, as shown in Figure 4-7, and are caused when the top layer of the asphalt shears and separates from the underlying material, often due to high deflections and a poor bond between the layers. This type of cracking cannot be effectively treated with crack sealants.

Figure 4-5 Reflection Cracking

Figure 4-6 Edge Cracking

Figure 4-7 Slippage Cracking

4.2 PROJECT SELECTION

Crack treatment may be an option for either surface preparation or surface sealing of a cracked HMA pavement. Projects are selected on the following criteria:

- The pavement structure should be sound.
- Cracks are only treated when greater than 1/4 inch (6 mm). or up to 1 inch (25 mm).

4.2.1 Project Planning

Ideally, crack-sealing treatments should be applied during relatively cool weather when the crack width is at its midpoint to widest, usually in the spring, fall, or winter. Weather conditions during installation need to be appropriate for the material used, not too cold or wet. Since non-working cracks do not change in width significantly with temperature, application of crack filling treatments can proceed at any time of the year when weather conditions are appropriate. Traffic passing over a hot applied sealed or filled crack is usually not an issue. However, traffic control during the application of the treatment should be in force long enough to allow for adequate curing of the product and prevent tracking. Before opening to traffic, apply sand or the manufacturer's recommended detackifying agent to tacky crack treatment material on the traveled-way. Sweep to remove excess sand prior to opening the lane.

4.2.2 Seal or Fill

The first question to be answered is whether to seal or fill a crack. Cracks may open and close horizontally with temperature and moisture changes and may undergo vertical movements as the result of load applications. Figures 4-8 and 4-9 illustrate these mechanisms of crack movement.

In order to determine whether to seal or fill a crack, it must be established whether the crack is working or non-working and whether the crack undergoes horizontal or vertical movement. The total horizontal movement of a crack over the period of one year is the primary determining factor of whether a crack is a working or non-working crack. The Caltrans criterion for a working crack is ≥1/4 inch (6 mm) of horizontal movement annually (Caltrans, 2000a); FHWA requires only 1/8 in (3 mm) (FHWA, 1999). Vertical movement is not usually considered (FHWA, 1999). Additionally, the width of the crack plays a role in deciding whether it is a working or non-working crack. Crack sealing is usually triggered when the crack width exceeds 1/4 in (6 mm). Also, the type of the crack can provide an indication of whether it is a working crack or not. Working cracks can be transverse or longitudinal to the pavement, but are most often transverse. Working cracks with limited edge deterioration should be sealed, rather than filled.

When the criteria for working cracks is not met, or when cracks are closely spaced and have little movement, crack filling is less expensive (FHWA, 1999). The criteria for deciding whether to seal or fill a crack are listed in Table 4-1.

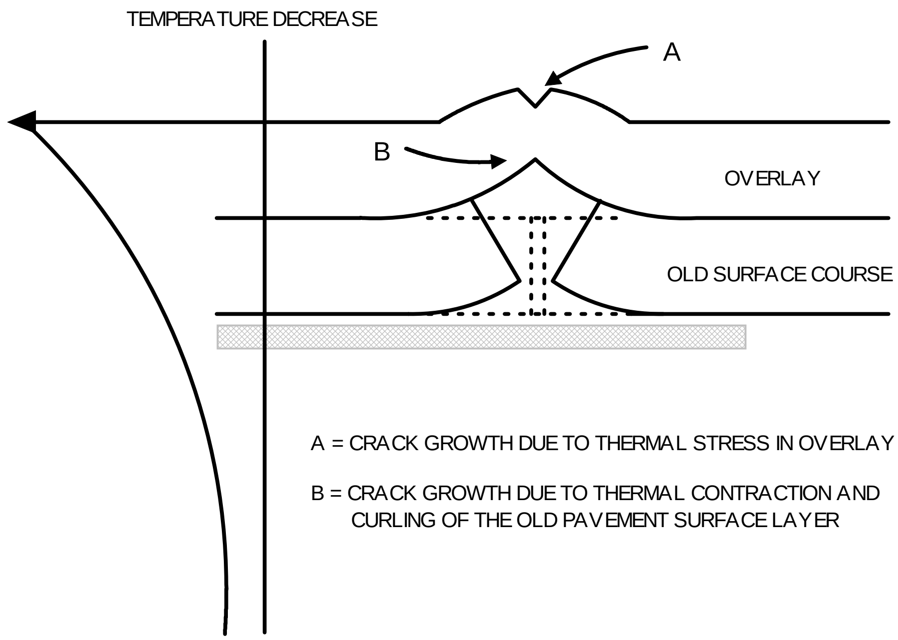


Figure 4-8 Thermal Effects on Crack Growth (Roberts, 1996)

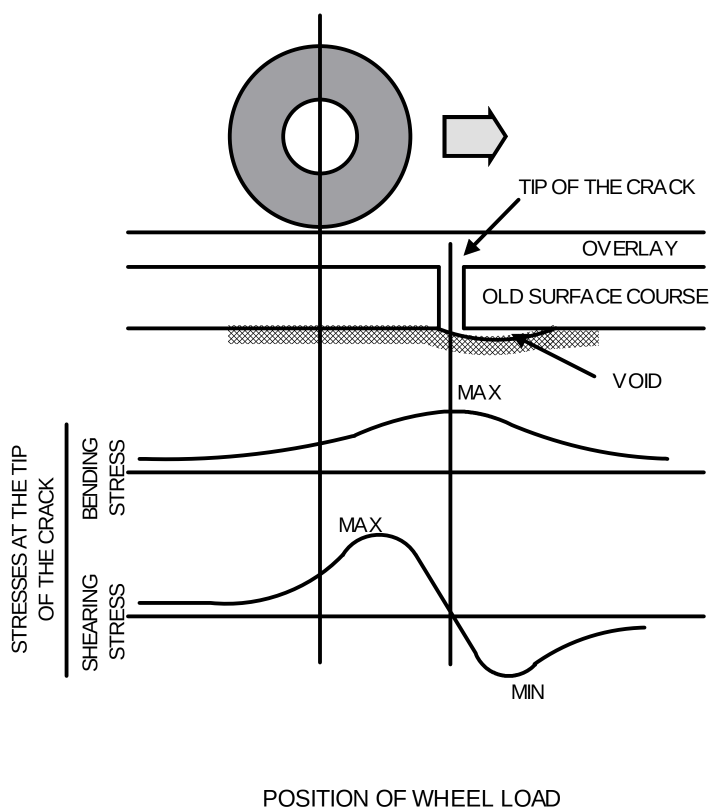


Figure 4-9 Traffic Load Effects on Crack Growth (Roberts, 1996)

Table 4-1 FHWA Criteria for Crack Sealing or Filling (FHWA, 1999)

CRACK CHARACTERISTICS	CRACK TREATMENT ACTIVITY	
	CRACK SEALING	CRACK FILLING
Width	0.12 – 1 in (3-25 mm)	0.12 – 1 in (3-25 mm)
Edge Deterioration	Minimal to None (<25% of crack length)	Moderate to None (<50% of crack length)
Annual Horizontal* Movement	≥ 0.12 in (3 mm)	< 0.12 in (3 mm)
Type of Crack	Transverse Thermal Cracks Transverse Reflective Cracks Longitudinal Reflective Cracks Longitudinal Cold Joint Cracks	Longitudinal Reflective Cracks Longitudinal Cold Joint Cracks Longitudinal Edge Cracks Distantly Spaced Block Cracks

* Annual Horizontal Movement is calculated by multiplying the distance between cracks times the typical annual temperature difference time the coefficient of expansion (0.0001in/in/ºC)

Crack Sealing

Crack sealing and filling prevent the intrusion of water and incompressible materials into cracks. The methods vary in the amount of crack preparation required and the types of sealant materials that are used.

Crack sealing is the placement of materials into working cracks. Crack sealing requires thorough crack preparation and often requires the use of specialized high quality materials placed either into or over working cracks to prevent the intrusion of water and incompressible materials. Crack sealing is generally considered to be a longer-term treatment than crack filling.

Due to the moving nature of working cracks a suitable crack sealant must be capable of:

- Remaining adhered to the walls of the crack
- Elongating to the maximum opening of the crack and recovering to the original dimensions without rupture
- Expanding and contracting over a range of service temperatures without rupture or delamination from the crack walls; and
- Resisting abrasion and damage caused by traffic

Section 4.3 discusses material requirements in detail.

Crack Filling

Crack filling is the placement of materials into nonworking or low movement cracks to reduce infiltration of water and incompressible materials into the crack. Filling typically involves less crack preparation than sealing and performance requirements may be lower for the filler materials. Filling is often considered a short-term treatment to help hold the pavement together between major maintenance operations or until a scheduled rehabilitation activity.

Crack filling is for active or non-active cracks created by ageing of the binder. Such cracks are not completely inactive and require some flexible characteristics. A suitable filler material must be capable of:

- Remaining attached to the walls of the crack
- Possessing some elasticity
- Resisting abrasion and damage caused by traffic

Section 4.3 discusses material requirements in detail.

4.2.3 Treatment Performance

The performance life of a treatment is affected based on the amount of crack preparation and the type of material used (FHWA, 1999). It has been found that depending on the amount of preparation and material selection, crack sealants can provide up to 9 years of service and fillers up to 8 years of service (FHWA, 1999). In California, overbanded treatments have contributed to poor ride, ride noise and poor surface appearance and are not recommended for use unless it has been squeegeed flush to the surface of the road. It should not be placed more than 1/2 inch (12.5 mm) wider than the width of the crack (on both sides of the crack).

Emulsions or asphalt materials placed in a flush configuration in unrouted cracks (see Section 4.3.4) can provide 2 to 4 years of service while hot applied rubber asphalt fillers placed in flush or overbanded configurations (Section 4.3.4) can provide 6 to 8 years of service (FHWA, 1999).

Several methods exist for evaluating a treatment's performance. One method is based on determining a treatment's effectiveness. Treatment effectiveness is the success of the treatment measured as a percentage of the total treatment that has not failed (FHWA, 1999). In order to determine the condition of a treatment, visual inspections of the treated areas are required. Inspections for treatment failure should be carried out once per year (FHWA, 1999).

Treatment Failures

Treatment failures can be attributed to improper treatment selection, improper material selection, poor workmanship, and improper application or lack of post-treatments. Common treatment failures include:

- **Adhesion loss:** The sealant does not adhere to the sides or bottom of the crack.
- **Cohesion loss:** The sealant fails in tension by tearing.
- **Potholes:** The crack is not completely sealed, allowing water into the pavement. Continued deterioration leads to pumping and pothole formation.
- **Spalls:** The edges of the crack break away as a result of poor routing or sawing.
- **Pull-on:** The sealant is pulled out of the crack by tire action.

Treatment Effectiveness

The first step in determining a treatment's effectiveness is establishing how much of the treatment has failed in relation to the total length of treatment applied (% failure). Once the amount of treatment failure is determined, the treatment's effectiveness can be calculated using the following expression (FHWA, 1999).

Effectiveness = 100 - % Failure…………………....……………………………….(2.1)

Where: % Failure = 100 X [Length of Failed Treatment / Total Length of Treatment]

By routinely monitoring treated areas, a graphical representation of a treatment's effectiveness can be generated like the one shown in Figure 4-10. From this figure, the projected life of the treatment used on this cracked area can be projected as the time at which the effectiveness has dropped to 50% (as defined above). Graphs like these can be used to determine when additional treatments may become necessary (FHWA, 1999).

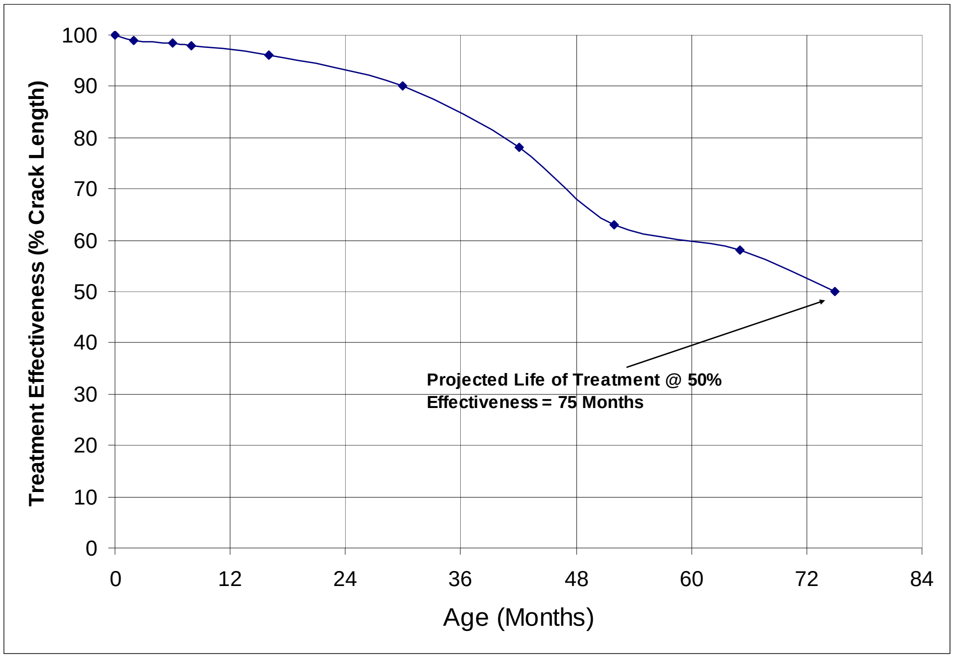


Figure 4-10 Treatment Effectiveness (FHWA, 1999)

Cost Effectiveness

The cost effectiveness of a treatment can be determined readily once the treatment effectiveness has been determined. Cost effectiveness is the total cost of a treatment divided by its effectiveness. Cost effectiveness may be converted into an annual cost by dividing the cost effectiveness by the number of years required to reach 50% effectiveness.

4.3 MATERIALS

Crack sealing and filling material specifications for Caltrans flexible pavements fall under SSP 37-400 (Caltrans, 2000b) and Standard Specifications Section 94 (Caltrans 1999a). The materials and methods discussed below apply to HMA pavements unless specified otherwise.

4.3.1 Materials and Specifications

Materials for Crack Treatment

Crack sealing materials are designed to adhere to the walls of the crack, stretch with the movement of the crack over the range of conditions and loads associated with the crack location, and resist abrasion and damage caused by traffic. For sealing working cracks, the preferred sealant is usually elastomeric. This means the sealant has a low modulus of elasticity and will stretch easily and to high elongations (usually around 10 times its non strained dimensions) without fracture. Such sealants also recover over time to close to their original dimensions. The sealants are usually applied at elevated temperatures due to their high viscosity at ambient temperatures and they set or cure by cooling and reforming into complex structures. This is called thermoplastic. Thermoset is sometimes used to describe these materials, however this is incorrect. A thermoset is a material that undergoes a chemical cross-linking when heated. This structure is retained as it cools and is not reversible by reheating. Thermoplastics form physical structures on cooling but this process is reversible with reheating. Hot application ensures good adhesive bond to the crack walls. In California most of the hot pour materials are rubber-modified asphalt. These materials have excellent abrasion resistance and are useful for trafficked surfaces. However they must be properly applied to perform as desired. For wider cracks (>1/2"), overbanding may become an issue. Other materials and placement methods (configurations) that have less tendency for causing bumps should be considered. Excessive application of sealer material causes similar problems.

For crack filling applications, the cracks are basically inactive (non-working). Crack filling materials are designed to adhere to the walls of the crack, and resist abrasion and damage caused by traffic.

Crack filling materials may be hot applied rubber or polymer asphalts, or cold applied emulsion-based products. The emulsion products assist with forming a good adhesive bond with the crack wall and additives such as Styrene Butadiene Rubber (SBR) latex ensure that the material can endure some degree of movement.

Table 4-2 lists Caltrans specifications for various crack treatment materials, based upon the climate zone in which it is to be used. Because many projects will contain both working and non-working cracks, Caltrans treats all cracks as working cracks and uses only crack sealing materials. The map of the Caltrans Pavement Climate Regions may be found at:
http://www.dot.ca.gov/hq/oppd/pavement/Pavement_Climateregions_100505.pdf

4.3.2 Storage and Handling of Materials

Chapter 2 of this guide identifies procedures for material storage and handling. In all cases, the manufacturer's recommendations for storage and handling should be closely followed.

Hot pour materials require very high temperatures, typically between 370 to 390°F (188 to 200°C) (FHWA, 1999). These materials may degrade or cross link when exposed to excessive temperatures for long periods of time. For this reason, the manufacturer's recommendations must be followed exactly.

Table 4.2 Crack Treatment Material

Climate Region		Deserts, slow moving traffic	Desert	South Coast, Central Coast, Inland Valleys	North Coast, Low Mountain, South Mountain	High Mountain, High Desert
Quality Characteristic [1]	ASTM Test Method [2]	Type 1 Material	Type 2 Material	Type 3 Material	Type 4 Material	Type 5 Material
Softening point (min.)	D 36	102 °C	96 °C	90 °C	84 °C	84 °C
Cone penetration at 77° F (max.)	D 5329	35	40	50	70	90
Resilience at 77° F, unaged, %	D 5329	20-60	25-65	30-70	35-75	40-80
Flexibility [3]	D 3111	0 °C	0 °C	0 °C	-11 °C	-28 °C
Tensile adhesion, %, (min.)	D 5329	300	400	400	500	500
Specific gravity (max.)	D 70	1.25	1.25	1.25	1.25	1.25
Asphalt compatibility	D 5329	Pass	Pass	Pass	Pass	Pass
Sieve test (percent passing)	See note 4	100	100	100	100	100

Notes:

[1] Cold-applied crack treatment material residue collected under ASTM D 6943, Method B and sampled under ASTM D 140 must comply with the grade specifications.

[2] Except for viscosity, cure all specimens at a temperature of 23 °C ± 2 °C and relative humidity of 50 ± 10 percent for 24 ± 2 hours before testing.

[3] For flexibility test, the specimen size must be 6.4 ± 0.2 mm thick x 25 ± 0.2 mm wide x 150 ± 0.5 mm long. Test mandrel diameter must be 6.4 ± 0.2 mm. Bend arc must be 180 degrees. Bend rate must be 2 ± 1 seconds. At least 4 of 5 test specimens must pass at the specified test temperature without fracture, crazing, or cracking.

[4] For hot-applied crack treatment, dilute with toluene and sieve through a No. 8 sieve. For cold-applied crack treatment, sieve the product as-received through a No. 8 sieve. If the manufacturer provides a statement that added components passed the No. 16 sieve before blending, this requirement is void.

4.3.3 Material Placement Methods

Once a suitable seal or fill material has been selected, as set forth in Caltrans Standard Special Provisions SSP 37-400 (Caltrans, 2000b), the appropriate placement method must be determined.

Placement methods vary according to the nature of the distress. When selecting the placement method, one should consider the method's applicability to: 1) the type of distress, 2) the dimensions of the crack channel, 3) the type of crack channel (cut or uncut), and 4) the finish requirements. Each method carries its own set of job equipment and preparation requirements. Typical placement methods used on flexible pavements include the following:

- Flush Fill
- Overband
- Reservoir
- Combination: Reservoir w/Band-Aid
- Combination: Sand Fill w/ Recessed Finish

Flush Fill Method

In the flush fill method, material is forced into an existing uncut crack. Once filled, the crack is struck off flush with the pavement. Figure 4-11 illustrates the flush fill method. When using thermoplastic materials, the crack should be filled to slightly below the surface to allow for expansion when hot.

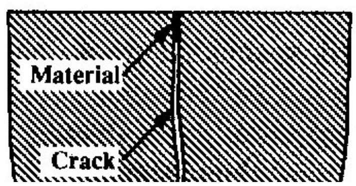
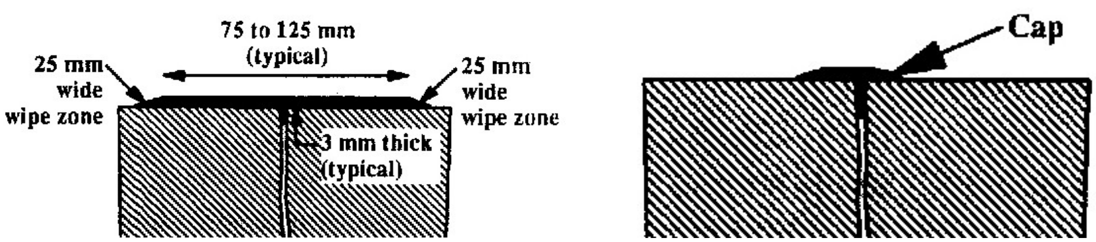


Figure 4-11 Flush Fill Method (FHWA, 1999)

Overband Method

In the overband method, material is forced into and placed over an uncut crack. If the material is squeegeed flat, it is referred to as a 'Band-Aid'; if not; it is referred to as capped. Figure 4-12 illustrates the overband method with both finishing options.



a) Simple Band-Aid b) Capped

Figure 4-12 Overband Method (FHWA, 1999)

Caltrans does not recommend this practice and advises that all crack sealing and filling be squeegeed if material is left above the surface. Overbanding can create a rough ride and/or excess road noise and causes problems (bumps and fat spots) when placing subsequent overlays, and therefore should be used only on low speed roads that will not be overlayed within in six months.

Reservoir Method

The reservoir method should be used for any project with working cracks. In the reservoir method, the crack is cut or routed to form a reservoir that is filled with a sealant. The sealant may be left flush or slightly below the surface of the reservoir. The depth and width of the reservoir varies according to job requirements. Saw depths will be greatest when working with very active cracks. Crack cutting will often depend on the number of cracks and whether the cutter can follow the shape of the crack. Typical reservoir widths range from 0.5 to 1.0 in (12 to 25 mm), and even up to 1.5 in (38 mm) in very cold climates. Reservoir depth ranges from 0.5 to 1.0 in (12 to 25 mm). Reservoir use is appropriate for pavements in good condition, without extensive cracking amounts. Crack cutting units, when operated by trained, experienced personnel, can follow meandering random cracks. Figure 4-13 illustrates the reservoir method. Table 4-3 shows recommend dimensions for routing (and sawing). Please note that the dimensions used are only approximations because the equipment does not make exact cuts.

Table 4-3 Recommended Crack Routing and Sawing Dimensions

Nominal Crack Width*	Rout or Saw Width	Rout or Saw Depth**	Width in Areas of temp extremes	Depth in Areas of Temp extremes**
¼ inch	½ inch	½ inch	1 inch	1/2in
3/8 inch	½ inch	½ inch	1 inch	1/2in
½ inch	¾ inch	¾ inch	1 inch	1/2in
5/8 inch	¾ inch	¾ inch	1.5 inches	¾ inch
¾ inch	No routing required	¾ inch***	1.5 inches	¾ inch
7/8 inch	No routing required	¾ inch***	1.5 inches	¾ inch
1 inch	No routing required	¾ inch***	1.5 inches	¾ inch
* Nominal crack width is the approximate width for 80% of the length of the crack				
** If using recessed fill method, add ¼ inch				
***Use sand fill or backer rod to limit material depth to ¾ inch				

Combination Method: Reservoir with Band-Aid

This combination method involves the formation of a 'Band-Aid' over the top of a cut reservoir. Figure 4-14 illustrates the combination method. Like the overband method, the combination method should not be used with materials that are prone to pickup due to traffic or materials with poor wearing characteristics (FHWA, 1999). The combination method can be used on heavily trafficked roads, but care must be taken to squeegee excess material off the surface.

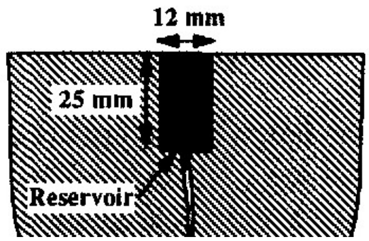


Figure 4-13 Reservoir Fill Method with Flush Finish (FHWA, 1999)

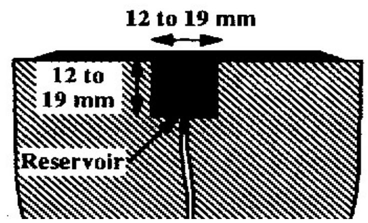


Figure 4-14 Combination Fill Method (FHWA, 1999)

Combination Method: Sand Fill with Recessed Finish

Thermal cracking can develop over time and penetrate the full depth of asphalt pavement in a roadway. As thermal cracks progress down through the asphalt layers, they typically continue to widen and it is not unusual for such cracks to be 0.5 to 1 in (12 to 25 mm) or wider and exceed 4 in (102 mm) in depth. If these types of cracks are sealed or filled full depth, the large volumes of filler or sealer tend to soften and migrate under loads in hot weather, and begin to pull out under traffic. If an overlay is applied, the heat of the new mat will draw the filler and sealer materials up through the overlay. In areas with heavy sealer or filler applications, fat spots, flushing, and shoving in the overlay can occur. These symptoms can only be remedied by changes in construction procedures or the removal and replacement of the affected materials.

Sealant application should not exceed 1 in (25 mm) in depth. For full depth wide cracks, backer rod can be used to limit sealant depth. Another method that can be used is to partially fill the crack with sand. Blow out any debris with air, fill the crack with clean sand to a point approximately 0.5 to .75 in (12.5 to 19 mm) below the adjacent pavement surface, and tamp lightly as needed with a steel rod or piece of rebar to reduce any large voids in the sand. Then apply the crack sealer over the top of the sand and along the crack faces so that the surface of the sealant is cupped slightly below the adjacent pavement surface. This recessed finish allows some movement of the crack and sealer material without creating an undesirable hump on the surface. This fills and seals the deep wide crack while limiting the impact on subsequent paving operations. Figure 4-15 illustrates this combination method.

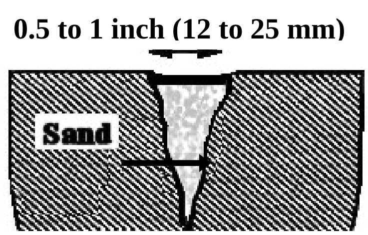


Figure 4-15 Combination: Sand Fill with Recessed Finish

4.3.4 Selecting the Appropriate Placement Method

The appropriate placement method should be based on the governing considerations of the project. Governing project considerations include:

- Type and extent of the sealing or filling operation
- Traffic conditions
- Crack characteristics
- Material requirements
- Desired performance (expectations)
- Aesthetics
- Cost

Table 4-4 outlines method placement issues in relation to governing project considerations.

Table 4-4 Placement Method Considerations (FHWA, 1999)

Project Consideration	Method Applicability
Type and Extent of Operation	Most filling operations, and some sealing operations, omit crack cutting operation. However, many northern States have found crack cutting necessary and desirable for cracks exhibiting significant movements.
Traffic	Overband configurations experience wear and, subsequently, high tensile stresses directly above the crack edges, leading to adhesive edge separations. Thus, overband configurations should be avoided for sealing cracks on heavily trafficked roads.
Crack Characteristics	If no overlay is planned, overband configurations may be appropriate for cracks having a considerable amount of edge deterioration (> 10 percent of crack length); because the overband simultaneously fills and covers the deteriorated segments in the same pass. However if it is possible that the pavement may be overlaid in the future, a scrub seal should be considered as an alternate method to address edge deterioration without overbanding.
Material Type	Materials such as emulsion and asphalt cement must be placed unexposed to traffic due to serious tracking or abrasion problems.
Desired Performance	For long-term sealant performance flush reservoir, and recessed band-aid configurations provide the longest life.*
Aesthetics	Overband and combination configurations detract from the general appearance of the pavement.
Cost	Omission of crack cutting operation reduces equipment and labor costs but may decrease treatment longevity. Combination configurations require significantly more material than reservoir configurations, resulting in higher costs. The placement method impacts the type of material to use as well so costs may be higher for specialty materials.

** Ride Quality is an important consideration*

4.4 CONSTRUCTION

4.4.1 Safety and Control

The Resident Engineer (RE) can examine and approve the contractor's traffic control plan prepared in accordance with the Caltrans Safety Manual (Caltrans, 1998) and the Caltrans Code of Safe Operating Practices (Caltrans, 1999d). The signs and devices used must match the traffic control plan. The work zone must conform to Caltrans practice and requirements set forth in the Caltrans Safety Manual and the Caltrans Code of Safe Operating Practices. All workers must have all required safety equipment and clothing. Signage shall be removed when it no longer applies.

4.4.2 Equipment Requirements

Equipment requirements vary according to the treatment method chosen. Equipment may be required for:

- Routing or Sawing
- Crack Cleaning and Drying
- Application of Sealer or Filler
- Finishing Method
- Trafficking and Subsequent Treatments

Equipment requirements are covered in more detail in Sections 4.4.4 through 4.4.7 of this chapter.

4.4.3 Climatic Conditions

Crack sealing treatments should be placed during relatively cool weather when the cracks are at their midpoint to maximum point of expansion. However this may conflict with prevailing weather conditions, as adherence of most high viscosity and emulsified crack fillers and sealants is limited at low temperatures. Fall is generally a good season for application in most parts of California , as air temperatures are typically between 45 to 65°F (7°C and 18°C). Under these conditions, cracks are usually at or near their mid-point of movement, which helps to ensure that the crack sealant or filler will not be extended or compressed too much when temperatures increase or decrease following application of the sealant or filler.

4.4.4 Preparation

Site preparation requirements vary according to the sealing or filling method and materials chosen for the project. The following paragraphs describe site preparation in further detail.

Routing or Sawing

When routing or sawing is incorporated, cracks need to be cleaned and dried prior to application of the filler or sealant. When pavements are cracked extensively, routing or sawing of cracks may not be appropriate. Some sort of scrub seal or chip seal might be a better solution. Crack cutting becomes especially important in climates where crack movement is very high. Crack cutting allows more filler to be used and provides better control of the crack channel shape. Secondary cracks along the primary crack are not usually routed. Routing is generally not used in HMA or PCC pavements in California. Crack cutting and routing equipment includes vertical spindle routers, rotary impact routers, and random crack saws. Damage to the pavement should be kept to a minimum by clean cutting. The use of carbide bits improves the quality of cutting and typically produces clean reservoir cuts. Figure 4-16 illustrates a rotary impact router in use.

Figure 4-16 Crack Routing Operation

Cleaning and Drying

Debris left in a crack, resulting from sawing, routing, or pavement use will affect the adhesion of the sealant or filler. Debris also contaminates the sealing or filling material and reduces cohesion. Reduced adhesion or cohesion normally results in early failures. To avoid these contamination-related failures, sawed or routed cracks must be cleaned prior to being treated. Several cleaning methods can be used, including:

- Air Blasting
- Hot Air Blasting
- Sand Blasting
- Wire Brushing

Air blasting involves directing a concentrated stream of air into the crack or joint to blow it clean. Air blasting equipment is effective and efficient for cleaning cracks, but not for drying them. Should a crack require drying, hot air blasting should be used. Air pressure should be a minimum of 97 psi (670 kPa) with a flow of 2.5 ft^3/s (0.07 m^3/s). Air blasting equipment must be equipped with moisture and oil traps.

Hot air blasting is done using a hot compressed air heat lance. While cleaning and drying the crack, hot air blasting also promotes enhanced bonding associated with the crack edges being warmed. Care must be taken to ensure that the pavement is not overheated or heated for excessive periods of time as this will result in unnecessary hardening of the asphalt binder in the pavement adjacent to the crack.

Wire brushing or brooming involves the use of a wire broom stock or stiff standard broom to brush out the crack or joint. Wire brushing can be an effective cleaning method. Wire brushing may be done manually or using power driven brushes. Figure 4-17 illustrates the manual crack cleaning method using a broom

Figure 4-17 Manual Crack Cleaning

Application of Sealer or Filler

The material selected will in part, determine the application method. Typically, asphalt emulsions are applied directly to the cracks. Hot applied rubber modified sealants, especially asphalt rubber, have excellent adhesion and do not require the application of a thin sand coating (blotter coat) prior to trafficking. Emulsions must be blotter coated prior to being trafficked. Emulsions may be applied via gravity feed devices, such as pour pots, or via pressure hoses. Some emulsions may require heating to achieve appropriate application viscosity. Hot applied rubberized sealants need to be agitated and heated and maintained at the correct temperature throughout their application. For polymer and rubber modified materials, control of temperature is important in preventing degradation. For hot applied fiber filled materials, the fiber may settle; therefore, agitation is required. For such materials indirect oil heating is recommended. Required capacity of sealant or filler application equipment is determined by the job size. Preheating the material before use is advisable to ensure productivity is optimized. Figure 4-18 illustrates a hot pressure feed sealing operation and a gravity fed pour pot.

a) Hot Pressure Fed b) Pour Pot

Figure 4-18 Application Techniques and Equipment

The application rate of a sealant or filler plays an important role in the quality of a crack sealing or filling project. Problems associated with over applied sealer or filler material include fat spots, localized tenderness, and flushing when treated areas are overlaid with hot mix.

4.4.5 Finishing

Finishing techniques will vary depending on the application and type of material chosen. Flush finishes and overbanding methods require the use of a squeegee. In some cases, a preformed plate on a hand lance assists in making the required flush result. Figure 4-19 shows three typical flat finishing techniques. As stated earlier, all sealant left on the surface shall be squeegeed to prevent a rough ride and is the only method recommended by Caltrans.

a) Squeegee b) Flat Plate Use c) Over Banding

Figure 4-19 Typical Flat Finishing Techniques

Blotter coats of clean sand are usually used with emulsion crack filling to prevent pick-up of an overband. A blotter coat is often used to prevent pick-up upon re-opening to traffic. To ensure a high quality blotter coat, only clean and dry sand should be used. Figure 4-20 illustrates the brooming of a blotter coat over a treated crack. This practice is not recommended by Caltrans as it leaves broom marks and voids in the sealant.

Figure 4-20 Brooming Blotter Coat Over a Treated Crack

4.4.6 Trafficking and Subsequent Treatments

Sealants and fillers undergo a curing cycle depending on the type of material used. Emulsions cure by water loss and reduce in volume. This process usually takes several days and creates a concave surface in the crack. Generally, cracks filled with these materials should not be overlaid for at least a year. Trafficking should not be allowed until after the emulsion has set sufficiently so that tires passing over the sealant/filler won't pick it up. Caltrans normally sands the sealer prior to opening to traffic.

Hot applied materials are thermoplastic; they set when they cool provided no diluents, such as solvents, are used in their formulation. These materials produce a non-tacky finish once the material reaches ambient temperature. A blotter coat can assist in this process. In addition, hot applied sealants require a three to four month cure time prior to being covered with a blanket or seal. Hot applied materials should not be placed over cold mix patches. This hot applied material will pick up, pulling the patch out.

4.4.7 Job Review – Quality Issues

Quality issues are typically related to the poor choice of sealing and filling methods and poor workmanship. Common examples of poor sealing and filling methods include excessive use of sealant and multiple uses of treatments over several years. One common example of poor workmanship includes over-filling without proper finishing. Figures 4-21 through 4-23 illustrate these commonly addressed quality issues. These practices directly impact traffic safety, smoothness and appearance for users.

Figure 4-21 Excessive Sealant

Figure 4-22 Multiple Treatments

Figure 4-23 Poor Workmanship – Raised, Bumpy Sealing

4.5 TROUBLESHOOTING AND FIELD CONSIDERATIONS

This section provides information to assist the maintenance personnel with troubleshooting problems with crack sealing and crack filling projects. The field considerations section discusses some field considerations to assist the development of successful jobs.

4.5.1 Troubleshooting Guide

The troubleshooting guide presented in Table 4-5 associates common problems to their potential causes. For example, a sealant separating from the sides of a crack may be caused by application to a wet crack surface, dirty crack surface, poor material finishing technique, application of cold sealant, insufficient material, rain during the application, or application during cold weather.

Table 4-5 Trouble Shooting Crack Sealing and Filling Projects

	PROBLEM						
	ALL SEALS			EMULSION SEALS ONLY			
CAUSE	Tacky Picks Up	Re-Cracks Quickly	Bumpy Surface	Separation From Crack Sides	Emulsion Sealer Not Breaking	Emulsion Sealer Breaks Too Fast	Emulsion Sealer Washes Off
Crack Wet					●		●
Sealant Not Cured	●			●		●	
Crack Dirty	●	●		●		●	
Insufficient Sanding	●			●		●	
Poor Finish, Wrong Tools	●	●	●	●		●	
Sealant Too Cold		●	●				
Sealant Too Hot	●			●			
Application Too High	●		●	●			
Application Too Low		●	●				
Sealant Degraded Due to Overheating	●	●	●	●	●	●	●
Rain During Application					●		●
Cold Weather		●			●		
Hot Weather	●		●	●		●	

In addition to the troubleshooting guide, Table 4-6 lists some commonly encountered problems and their recommended solutions.

Table 4-6 Common Problems and Related Solutions

Problem	Solution
Tracking	• Reduce the amount of sealant or filler being applied. • For hot applied materials, allow to cool or use sand or other blotter. • Allow sufficient time for emulsions to cure or use a sufficient amount of sand for a blotter coat. • Ensure the sealer/filler is appropriate for the climate in which it is being placed.
Pick out of Sealer	• Ensure cracks are clean and dry. • Increase temperature of application. • Use the correct sealant for the climate. • Allow longer cure time before trafficking.
Bumps	• Check squeegee and ensure it is leaving the correct flush finish. • Have squeegee follow more closely to the application. • Decrease the viscosity of the sealer. • Change the rubber on the squeegee. • Stop using overbanding.

4.5.2 Field Considerations

The following field considerations are a guide to the important aspects of performing a crack sealing or crack filling project. The various tables list items that should be considered in order to promote a successful job outcome. As thoroughly as possible, the answers to these questions should be determined before, during, and after construction. The staff to do this work will vary by job type and size. Some topics may need attention from several staff members. The field supervisor should be acquainted with its contents. The intention of the tables is not to form a report, but to bring attention to important aspects and components of the project process. Some information is product specific and contained in the relevant standard specifications, special standard provisions, or special provisions.

PRELIMINARY CONSIDERATIONS	
PROJECT REVIEW	• Is the project a good candidate for crack sealing or filling? • What type of cracking exists? How severe is it? How much is there? • Are there base failures along the project? • How much bleeding or flushing exists? • Is the pavement raveling or oxidized? • What is the traffic level? • Is the base sound and well drained? • Would a membrane (SAM, SAMI) or scrub seal treatment be a better solution? • Review project for bid/plan quantities.
DOCUMENT REVIEW	• Crack activity (movement) information • Application specifications • Construction manual • Special provisions • Traffic control plan
DETERMINING APPLICATION TYPE	• What type of application is being used? • Are agency guidelines and requirements being followed? • Are the cracks being sawn or routed? • Is a bond beaker being used?
MATERIAL CHECKS	• Has a crack survey been done? • Has the amount of filler/sealer material required been calculated for the number and length of cracks being treated? • Has the sealer or filler been produced by an approved source? (if required) • What is the application temperature and the safe heating temperature? • What special handling requirements are needed: heating rate, allowable storage time at high temperatures, cold application? • Has the sealer or filler to be used been sampled and submitted for testing? • Is a blotter coat required? Is clean, dry sand available?

PRE-SEAL INSPECTION CONSIDERATIONS	
SURFACE PREPARATION	• Do the cracks need to be sawn or routed? • Are secondary cracks to be sawn or routed? • Have the cracks been cleaned? • Have oily residues been scrubbed from the pavement? • Has the surface been cleaned, dried, and broomed?
WEATHER REQUIREMENTS	• Air and surface temperatures have been checked at the coolest location on the project? • Air and surface temperatures meet agency and sealant/filler manufacturer requirements. • Application should not begin if rain is likely. • Application should not begin if freezing temperatures are expected.
TRAFFIC CONTROL	• The signs and devices used match the traffic control plan. • The work zone complies with Caltrans traffic control policies as described in the Caltrans Safety Manual (Caltrans, 1999c). • Flaggers do not hold the traffic for extended periods of time. • Unsafe conditions, if any, are reported to a supervisor. • Signs are removed or covered when they no longer apply.
EQUIPMENT INSPECTION AND CONSIDERATIONS	
SAWING/ ROUTING UNIT	• Is a saw or router to be used? • Is the unit fully functional? • Are the cutting bits sharp to avoid spalling or cracking? • Are the cutting bits the correct size? • Is all equipment free of leaks? (Hydraulic oil, diesel, motor oil etc.)
SEALING UNIT	• Is the sealing unit functional? • Are the moisture and oil filters on the compressor clean and functioning? • Does the unit have temperature control (for hot applied sealants)? Is the temperature controller working properly and is the measuring device calibrated? • Does the sealing unit provide adequate pressure to deliver material to the crack at an appropriate rate? • Is a pour pot being used? • Is a kettle applicator being used? Is the kettle being kept at least partially full at all times? • Is the applicator unit re-circulating during idle periods? • What method is being used to ensure that the crack sealant or filler is flush with the pavement surface? • Is all equipment free of leaks? (Hydraulic oil, diesel, motor oil etc.)

PROJECT INSPECTION CONSIDERATIONS	
CRACK SEALING OR FILLING APPLICATION	• Does the operator have safety gear appropriate for the job? • Do the cracks need to be mapped? • Does the cutting/routing follow the crack as closely as possible? • Are cut dimensions satisfactory? • Are the cracks dry at the time of sealing? • The sealing operation must follow directly behind the cutting/cleaning/drying operations? • Sealant flows evenly with no surging? Vat to be kept at least part full at all times. • Is the sealant at the correct application temperature? • Check sealant temperature at nozzle using high temperature thermometer or infrared thermometer. • Is the squeegee shape correct and not worn, clean and free of carbon or filler build up, operated at the correct distance from the crack, and centered on the crack? • Sealant is even and consistent and has not been reheated more than the allowable number of times and for the recommended periods of time? • Are there excessive bubbles in the material caused by water? • Confirm that crack channel is filled from the bottom up and not overfilled. • Does the application have an even and uniform finish, flush with the pavement surface? • Reapply sealant to any areas that are under filled. • The application is stopped as soon as any problems are detected. • Check bond by peeling the filler or sealant. • Do not traffic until the sealant or filler does not track under traffic.
CLEAN UP	• All material spills are cleaned up. • All loose sand is removed from the traveled way.

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CHAPTER 5 PATCHING AND EDGE REPAIR

5.1 OVERVIEW

Patching, one of the most expensive of the maintenance procedures for hot-mix asphalt (HMA) pavements, (per unit of measure such as cost/ton, cost/in^2, or cost/yd^2) and is often done in preparation for other forms of corrective maintenance, pavement preservation, or pre-treatment prior to an overlay. Patching restores the pavement surface to a state where other preservation treatments can be used with a good chance of success.

The primary methods of patching include the replacement of materials that have been lost due to localized pavement distress or disintegration, the complete removal (dig out) and replacement of continuous segments of failed pavement, or the application of a thin layer of HMA material over segments of pavement that exhibit more surface-related distress/distortion. Once patched, the distressed area is repaired or strengthened so that it can carry a significant traffic level with improved performance and lower rates of deterioration.

Patching may be temporary, semi-permanent, or permanent treatments. The appropriate method to be used depends on the traffic level, the time of the year during which the repair is carried out, the time until scheduled rehabilitation, and the availability of equipment and personnel.

Patching is best carried out during clear moderate weather. However, emergency repairs may require patching be performed during poor winter weather conditions. In these instances, the durability of the patch is likely to be poor and the patch should be considered to be temporary. Accordingly, it is a good strategy to plan for a more semi-permanent repair of these areas when moderate weather conditions prevail.

This chapter is divided into pothole patching, material dig out and replacement, edge repair, and surface reinstatement. The procedures and materials associated with each method are addressed in a similar fashion.

5.1.1 Patching

Patching is a process in which the material in a highly distressed area is either removed/replaced or additional material is added to cover up the distressed area. Merely filling a hole will not prevent the development of distress adjacent to or within the patch in many instances. Maximum performance is achieved when the boundaries of the distressed area are appropriately marked and cut, the failed material is removed, the remaining (underlying) material is recompacted, the hole is properly prepared, and new material is added and compacted to a level similar to that for a new pavement.

The primary methods used to perform pothole patching are:

- Temporary
- Semi-Permanent
- Injection Patching (Not yet widely used in California)

The primary materials used for pothole patching are:

- Hot-mix Asphalt (HMA) - preferred
- Cold-mix Asphalt – temporary fix only
- Aggregate/Asphalt Emulsion Combinations (i.e., injection patching)
- Special Patching Mixtures

5.1.2 Dig Outs

Dig outs are used when the pavement has failed in localized areas to an extent that the underlying support materials have disintegrated, become infiltrated with fine-grained materials, or otherwise lost their load-carrying capacity. Unlike typical patching, dig outs require the removal and replacement of much (if not all) of the underlying base/sub base materials. Due to the thorough nature of this method, it has sometimes been referred to as spot reconstruction.

The main steps associated with dig outs are:

- Marking and cutting of the boundaries
- Breakup and removal of the pavement surface and affected base/sub base layers
- Placement and compaction of new base/sub base layers
- Application of tack coat along the edges of the repair area
- Placement and compaction of new asphalt surface

The main materials used for dig outs are:

- Hot-mix Asphalt (HMA) - preferred
- Cold-mix Asphalt – emergency fix only

5.1.3 Edge Repairs

Edge repairs are used when the pavement has failed along the edges due to the action of traffic and the loss of edge support that occurs due to the presence of water, aggressive-growth vegetation, and wind from either traffic or the atmosphere. The main materials and methods used in edge repairs are the same as those associated with patching and dig outs.

5.1.4 Surface Reinstatement

The main method used for surface reinstatement is skin patching. Skin patching does not require a dig out. Typically, either a thin layer of HMA or a cold mix blanket can be applied to the existing surface or a coat of spray binder (emulsion) is applied and covered with a layer of aggregate. Aggregate is either washed sand or fine aggregate (0.1 to 0.2 in [3 to 5 mm]) compatible with the emulsion being used. HMA skin patches are rolled with a light hand roller, while spray-on patching is rolled using the maintenance truck wheels.

5.2 PROJECT SELECTION

5.2.1 Potholes

Potholes are a form of disintegration of the pavement that may be associated with poorly compacted material, raveling, cracking, base failure or aging of the pavement. Potholes often appear after rain or during thaw periods when pavements are weaker. The generally accepted mechanisms for pothole formation are as follows:

- Raveling, stripping, or cracking occurs in the pavement surface.
- Water penetrates the surface layers of the pavement, softening the underlying pavement layers, which increases deflections. Figure 5-1 illustrates how water can penetrate a pavement.
- Ice formation and heaving in the pavement occurs in some climatic areas. Figure 5-2 illustrates heaving due to a freeze-thaw cycle in a cold climate.
- Fines from the underlying pavement layers are lost, reducing overall structural strength and support for the pavement surface. Figure 5-3 illustrates the resulting cavity when the fines are lost due to migration or pumping.
- Once a hole is formed, it will continue to grow until it is repaired. Figure 5-4 illustrates the role traffic plays in enlarging a pothole.

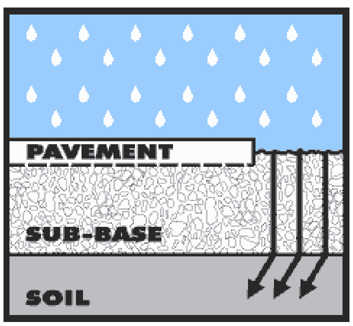

Figure 5-1 Water Penetration of Pavement (MDOT, 2001)

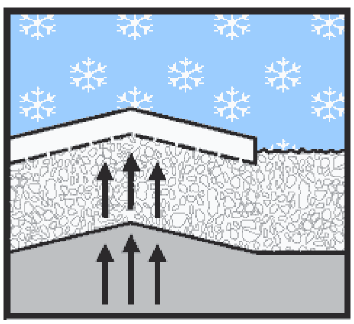

Figure 5-2 Heaving Effects Caused by the Freeze/Thaw Cycle (MDOT, 2001)

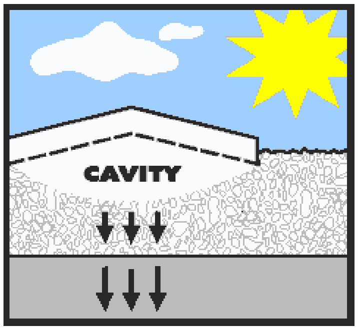

Figure 5-3 Loss of Fines Results in a Void Under the Pavement (MDOT, 2001)

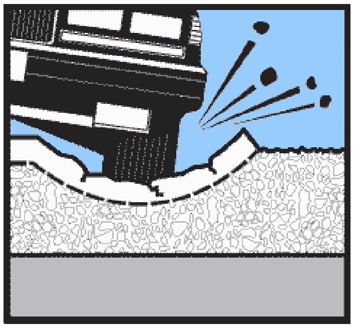

Figure 5-4 Once Formed, Traffic Enlarges Potholes (MDOT, 2001)

5.2.2 Edge Failure

Edge failures occur when the edge of a pavement breaks up which is caused by traffic loading at the edge of the pavement (usually due to a horizontal geometry problem) and/or the infiltration of water at the edges of the pavement or shoulder. Although edge failures are usually out of the primary wheel paths, their presence can accelerate the normal deterioration of the pavement in the traveled way.

5.2.3 Costs and Performance

The main costs associated with patching include:

- Labor
- Materials
- Equipment
- Traffic Delays

Cost effectiveness is determined by the patch survival rate. To determine the patch survival rate, repairs should be monitored for at least one year. Monitoring consists of checking for the presence of repairs and noting the survival or failure of each pavement section. Figure 5-5 shows typical survival rate curves, where A, B and C represent three separate patch locations. The area under the curve represents the patch survival rate.

Dig outs are generally carried out using larger equipment and are the most expensive method of patching. The effectiveness of dig outs is determined in the same manner as described for patching above.

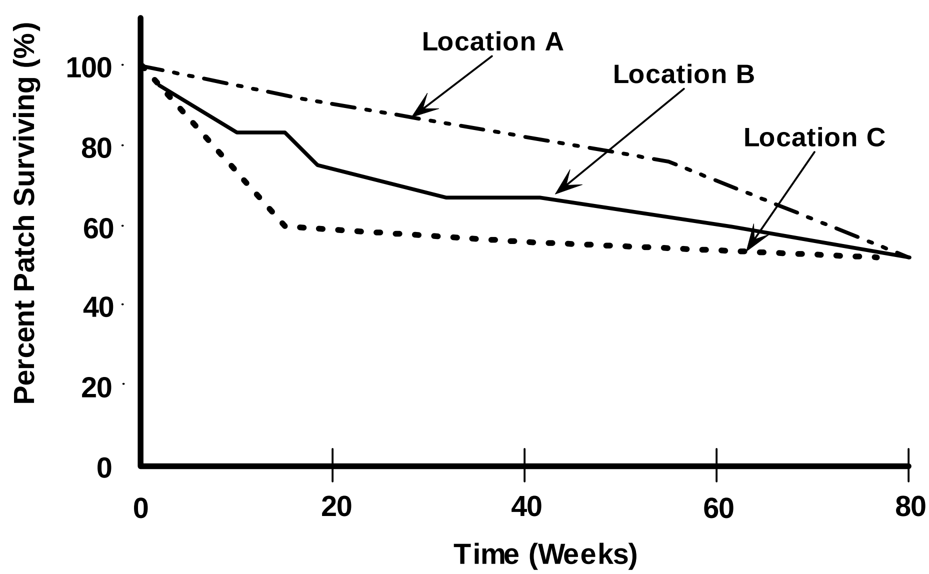

Figure 5-5 Typical Survival Rate Curves (FHWA, 1999)

5.2.4 Design and Specifications

Patching design and specification is based on procedures of application and the use of appropriate materials. The materials should be tested according to the related Caltrans specifications. Generally HMA materials are specified based on Caltrans Dense-Graded Asphalt Concrete (DGAC) specifications as presented in Standard Specifications Section 39 (Caltrans, 2006). However, the mix type used may vary according to traffic conditions.

Caltrans also uses cold-mixes for patching. These are generally proprietary products and should be handled according to the manufacturer's specifications.

5.3 CONSTRUCTION

5.3.1 Patching

Construction procedures for pothole patching vary according to the method and materials selected. The three primary patching techniques along with edge sealing technique are described below. Section 5.4.2 (Field Considerations) provides a series of tables to guide project personnel through the important aspects of performing a patching or edge repair project.

Throw and Roll

The "throw and roll" method is often used for temporary patches. This is only appropriate when weather conditions are too poor for a semi-permanent patch to be placed or the road is due to be rehabilitated soon. It is the least expensive and least labor-intensive method for patching a pothole and includes the following steps:

- Patching material is placed into the hole, with or without cleaning and/or drying of the hole.
- The material is compacted using the maintenance truck tires.
- The finished patch should have $^{1}/_{8}$ to ¼ in (3 to 6 mm) of crown to help avoid water ponding.
- Clean-up is generally not required.

Figure 5-6 illustrates a typical throw and roll application.

Figure 5-6 Throw and Roll Patching

Semi-Permanent Patches

Semi-permanent patching is considered to be an effective patching method (second only to complete removal and replacement of the failed area). The following steps describe how this form of patching is carried out:

- Mark the boundaries of the distressed area (Figure 7), taking care to encompass a slightly larger area than that reflected by the distress. The repair boundaries should be as rectangular as possible and take into consideration the dimensions of the equipment that will be used for removal of the old material and compaction of the new material.

- Cut the boundaries of the patch square using either a diamond saw or pneumatic hammer with a spade bit. In the case of the latter, care should be taken not to damage the HMA surface layer in the sound pavement.

- Square up the sides of the hole until the edges of the hole are sound pavement. This step is usually very simple if the boundaries of the repair area were cut with a diamond saw or established with cold milling equipment. It is usually only required when manual techniques of material removal are employed. Figure 5-8 illustrates a hole that has been extended to sound pavement and firm supporting material. It is suggested that the depth of the patch be 50% thicker than the thickness of the failed layer.

- Remove water and debris from the hole. Depending on the size of the pothole, this may be accomplished manually with a pick and shovel or with various combinations of power equipment, i.e., a pneumatic hammer and shovel, backhoe, or front-end loader. Cold milling equipment can also be very effective for this operation.

- Apply a tack coat of asphalt emulsion to the sides and bottom of the hole at a rate of approximately 0.2 gal/yd^2 (1 liter/m^2) using a slow or rapid setting emulsion. The tack coat should either be sprayed or brushed on the edges of the repair, never poured. Figure 5-9 illustrates the tack coat application.

- Place the patch material in the hole. If the patch is placed manually, use a shovel (not a rake) to place the HMA material taking care to avoid segregation. The hole should be overfilled by 20 to 25 percent of its depth to provide adequate material for compaction. An asphalt rake should be used to feather or blend the patch edges.

- Compact the patch material with a hand device or a small vibratory roller. It is preferable to use compaction equipment whose surface is smaller than the size of the patch. It is very difficult to achieve satisfactory compaction with equipment that bridges the repair area. Figure 5-10 illustrates the compaction of the patch material.

- The patch should be compacted thoroughly with proper compaction equipment. For additional compaction by traffic and helps prevent standing water accumulate in the patch area, the finished patch should have a 0.1 to 0.2 in (3 to 6 mm) crown, as illustrated in Figure 5-11.

- The edges of the patched area should be sealed with crack sealant. For areas with significant amount of rainfall, the entire patch should be fog sealed.

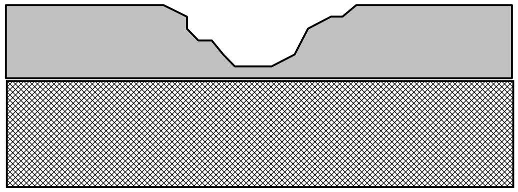

Figure 5-7 Pothole Area

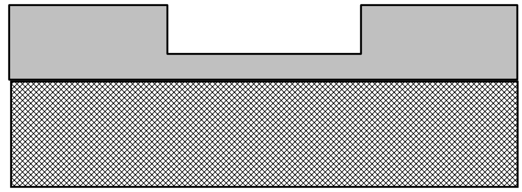

Figure 5-8 Surface and Base of Pothole Prepared for Treatment

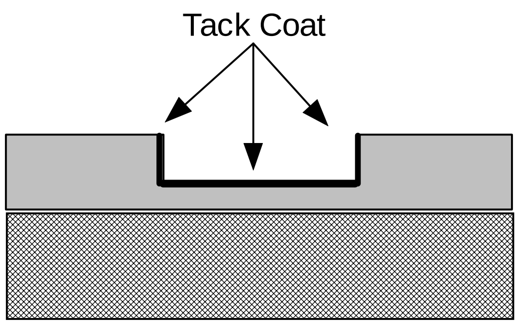

Figure 5-9 Tack Coat Applied to All Sides of Hole

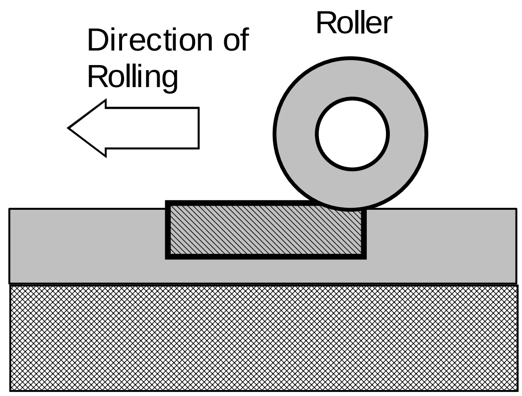

Figure 5-10 Patch Material Placed and Compaction in Progress

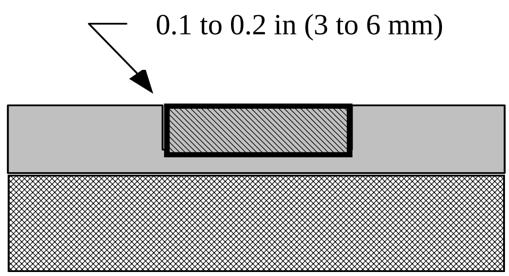

Figure 5-11 Finished Patch with a 0.1 to 0.2 in (3 to 6 mm) Crown

Injection Patching

Injection patching is a rapid and effective method of patching that requires specialized equipment. This method, not currently used by Caltrans, is used for lower trafficked roads and is an alternative to the throw and roll method. These patches are temporary, but generally have a longer life than throw and roll patches (FHWA, 1999). The steps for injection patching are described below:

- Prepare the site for patching by blowing debris and water from the hole with the application nozzle. Figure 5-12 illustrates site preparation.
- Spray a tack coat of emulsion on the sides and bottom of the hole at a rate of approximately 0.2 gal/yd^2 (1 liter/m^2). Figure 5-13 illustrates the application of a tack coat.
- Blow asphalt/aggregate mixture into the hole, filling the hole to the top. Figure 5-14 illustrates filling the prepared hole.

- Finish with a layer of dry aggregate. Figure 5-15 illustrates the application of a finish coat to minimize pick up. Note: It is not necessary to roll a pothole patched using this method. This is one advantage of the injection method.

Figure 5-12 Site Preparation

Figure 5-13 Application of Tack Coat

Figure 5-14 Filling the Prepared Hole

Figure 5-15 Application of Finish Coat

Edge Sealing

To improve the durability of a patch, the edge of the patch should be sealed to prevent the intrusion of water and other debris. Edge sealing refers to the application of asphaltic material along the edges of a patch. Once set, this ensures that water cannot penetrate the patch seam. Sealing materials may be rubberized to allow for differential movement between the existing pavement material and the new patch material. Figure 5-16 illustrates a finished edge seal application.

Figure 5-16 Edge Seal Application

5.3.2 Dig Outs

When the edge of the pavement has broken away or the base has failed due to severe alligator cracking, the complete removal (dig out) of failed asphalt and base materials is typically required. Dig out selection is important, as areas that fail due to alligator cracking will produce reflective cracks through new surface treatments if the distressed pavement is not replaced. When in doubt, a dig out should be performed.

The typical dig out construction process is as follows:

- Mark the boundaries of the distressed area to be replaced. Strive for rectangular areas taking into consideration the dimensions of the equipment that will be used for removal of the failed material and compaction of the new material.
- Cut out the perimeter of the area with a diamond saw or cold milling machine.
- Break up and remove the failed pavement to the subgrade material using appropriate combinations of pneumatic hammers, backhoes, front-end loaders, and cold milling equipment.
- Clean and dry the dig out area.
- The dig out area should allow sufficient new HMA materials (at least 50%, preferably 100% of the existing AC thickness) to be placed for adequate compaction. If the depth of the dig out area is more than twice the thickness of the existing AC layer, place and compact new (virgin) base course material using appropriate combinations of front-end loaders and roller compaction equipment.
- Apply a tack coat of emulsion using a rate of approximately 0.2 gal/yd^2 (1 liter/m^2) to the sides of the repair area. Tack may also be placed along the bottom of the repair area if local experience indicates good performance. Place the patch material in the prepared dig out area.
- Generally larger aggregates ½ to ¾ in (12 to 19 mm) are used for dig outs because of their thickness. Place the patch material in the prepared dig out area. Note: HMA is typically used as the patch material. AR-8000 should be used if the area has a history of pushing or shoving.).
- The patch material is typically placed in lifts if the depth of the repair is greater than 4 in (100 mm). The thickness of any lift should not exceed 4 in (100 mm). The final lift should be made using enough material that 3 to 4 roller passes are required to roll the patch flush with the old pavement.
- Compact each lift using equipment similar to that typically used in hot-mix asphalt compaction operations. The width of the compaction equipment should be narrow enough to fit within the repair area. Equipment that bridges the repair area is less likely to achieve adequate compaction of the HMA material (Note: Caltrans allows wheel rolling in all lifts except the top lift).
- The finished patched area should have a crown of $^1/_8$ to ¼ in (3 to 6 mm).

Figure 17 illustrates a completed dig out project. Before the new pavement is open to traffic, it is recommended that the edges are seamed with crack sealant and the entire patch is fog sealed.

Figure 5-17 Dig Out Project

5.3.3 Edge Repairs

The basic construction steps associated with a repair along the edge of the pavement depend upon the severity and depth of the deterioration. If the distress is confined mainly to the HMA surface, then the steps associated with a regular patching operation should be employed. If, on the other hand, the deterioration extends well below the surface, then the steps associated with a dig out are more appropriate. In both cases, the intent is to provide improved lateral support along the pavement's edge. Accordingly, extra precautions should be taken for achieving adequate compaction and maintaining good drainage at that interface with the shoulder.

5.3.4 Surface Reinstatement

Choosing the appropriate skin patching method depends largely on what materials are available. Table 5-1 summarizes three typical approaches.

Table 5-1 Approaches for Surface Reinstatement

METHOD A: HMA APPLICATION
• The area to be patched is cleaned of debris. • A diluted tack coat emulsion is applied at a rate of approximately 0.1 gal/yd^2 (0.5 l/m^2) • The HMA is laid over the surface and spread. The HMA thickness should be a minimum of three times the largest aggregate size. • The HMA is then initially compacted using a vibratory roller, subsequent compaction with a pneumatic roller and finished with a steel roller.
METHOD B: EMULSION SEAL COAT
• The area to be patched is cleaned of debris. • A tack coat emulsion is applied at a rate of approximately 0.2 gal/yd^2 (1 l/m^2). • A layer of sand or fine aggregate, typically 0.1 to 0.2 in (3 to 5 mm) in depth, is applied. • The patched area is then rolled with a pneumatic tired roller.
METHOD C: COLD MIX
• The area to be patched is cleaned of debris. • A light tack coat of diluted emulsion is applied at a rate of approximately 0.1 gal/yd^2 (0.5 l/m^2). • Spread mix over area to be repaired to a depth of 1 in (25mm). • Compact mix using a pneumatic tire roller (or haul trucks) and finish with a steel wheel roller. • Follow up before winter with a fog seal.

5.4 TROUBLESHOOTING AND FIELD CONSIDERATIONS

5.4.1 Troubleshooting Guide

This section provides information to assist maintenance personnel with troubleshooting problems with patching and edge repair projects. Table 5-2 outlines common problems and related solutions.

Table 5-2 Common Patching Problems and Related Solutions

PROBLEM	SOLUTION
PATCHING MATERIAL PICKS OUT	• Ensure the hole is cleaned properly and not too wet. • Ensure sufficient tack coat is applied. • Use a self-setting cold-mix when holes cannot be dried properly. • Ensure the patch is solid before trafficking. • Dust patch surface with sand or small aggregate. • Wait for better weather. • Do not use cutback based cold-mix (unless a temporary repair is being done). • For HMA patches, allow to cool before traffic is allowed over the patch. • Ensure required compaction is achieved.
FLUSH SURFACE	• Reduce asphalt or emulsion content in the mix. • Reduce tack coat application. • Allow longer time before trafficking. • Ensure the gradation of the aggregate is appropriate.
UNEVEN SURFACE	• Ensure cold-mix is workable. • Ensure HMA is at the right temperature for placement and compaction. • Ensure adequate compaction is achieved.
LOSS OF COVER ROCK IN SEAL COAT PATCHES	• Ensure surface is clean. • Ensure correct emulsion content is sprayed. • Ensure aggregate is spread while the emulsion is still brown. • Ensure emulsion is broken before traffic is allowed. • Allow longer cure time before traffic.
TRAFFIC COMPACTS MIX TO BELOW EDGE OF HOLE	• Ensure finished hole is overfilled 0.1 to 0.2 in (3 to 6 mm). • Ensure adequate compaction is achieved. • Ensure mix is workable at application temperatures. • Allow longer time before trafficking.

5.4.2 Field Considerations

The following field considerations are a guide through the important aspects of performing a patching or edge repair project. The various tables contain items that should be considered in order to promote a successful job outcome. Thorough answers to these questions should be determined, as required, before, during, and after construction. The appropriate staff to do this will vary by job type and size. Some topics may need attention from several staff members. The contractor or maintenance field supervisor should be acquainted with its contents. The intent of the tables is not to form a report, but to bring attention to important aspects and components of the project process. Some information is product specific and contained in the relevant standard specifications, standard special provisions, or special provisions.

PRELIMINARY RESPONSIBILITIES	
PROJECT REVIEW	• What is the extent of the potholes? • What caused them? • Is base failure extensive? • Are pothole patches or dig outs required? • Will a surface treatment be needed after the repair? • What is the traffic level? • Is the majority of the base sound and well drained? • What time of year will repairs be performed? • Is a temporary or permanent patch required? • Will the patch require an edge seal? • Review project for quantities of materials required.
DOCUMENT REVIEW	• Material specifications. • Dig out / patching methods • Required special provisions • Construction manual • Traffic control plan (TCP)
MATERIAL CHECKS	
EMULSION INJECTION OR COLD-MIX PATCHING	• Are the materials compatible with the job requirements? • Is the emulsion produced by an approved source? • Has the delivered emulsion been sampled and submitted for testing? • Does the aggregate meet all specifications and is clean and free of deleterious materials (sand equivalent)? • Is the aggregate damp, but not wet? • Is the emulsion warm to the touch but not hot? • Is the tack emulsion suitable for the climatic conditions? • Is the cold-mix within specifications? • Is the cold-mix workable at the required temperatures?

MATERIAL CHECKS	
SPECIAL COLD-MIX PATCHING	• Are materials compatible with the job requirements? • Are the materials within specification? • Is the tack emulsion within specification?
HMA PATCHING	• Are the materials compatible with the job requirements? • Is the tack emulsion produced by an approved source? • Has the delivered emulsion been sampled and submitted for testing? • Is the HMA made to specification? • Is the HMA workable in the climatic conditions used?
DIG OUTS AND EDGE REPAIRS	• Are the materials compatible with requirements? • Is the emulsion produced by an approved source? • Has the delivered emulsion been sampled and submitted for testing? • Is the mix used for reinstatement within specification? • Is the base course material within specification?
SKIN PATCHING	• Are the materials compatible with requirements? • Is the emulsion produced by an approved source? • Has the delivered emulsion been sampled and submitted for testing? • Is the aggregate clean, dry, and properly graded? • Is the base course material within specification?
PRE-SEAL INSPECTION RESPONSIBILITIES	
SURFACE PREPARATION	• Are the edges of potholes or dig outs straight and free of debris? • Has the existing surface been inspected for drainage problems? • For dig outs, has all failed material been removed?
EQUIPMENT INSPECTIONS	
INJECTION PATCHING MACHINE	• Is the machine fully functional? • Is the equipment free of leaks (hydraulic oil, diesel, motor oil, etc)? • Does the aggregate flow freely? • Does the emulsion flow freely? • Is the compressor working properly?

DIG OUT COLD PLANERS	• Is the machine fully functional? • Are the cutting tips sharp and do they make a clean cut without spalling the edges? • Is the equipment free of leaks (hydraulic oil, diesel, motor oil etc)?
EQUIPMENT INSPECTIONS	
POTHOLE PATCHERS – HMA/COLD-MIX	• Is the equipment free of leaks (hydraulic oil, diesel, motor oil etc)? • Are heating systems working and able to accurately control mixing temperature? • Are all conveyors working? • Are the hoses for applying tack coat working properly? Is the tack coat being applied at the correct rate?
SKIN PATCHING	• Is the equipment free of leaks (hydraulic oil, diesel, motor oil etc)? • Are the heating systems working and accurately controlling the mix temperature? • Can the hand spray line or boot truck spray be properly controlled? • Is aggregate spreading being properly controlled?
COMPACTION DEVICES	• Is the equipment free of leaks (hydraulic oil, diesel, motor oil etc)? • Are tandem or other rollers in working order and meet specification requirements? • Are compaction measurement devices (such as nuclear gages) in working order?
WEATHER REQUIREMENTS	• Have the air and surface temperatures been checked at the coolest location on the project and do they meet agency requirements. • Application of patching does not begin if rain or snow is likely. • Emulsion type applications should not start if freezing temperatures are expected.
TRAFFIC CONTROL	• The signs and devices used match the traffic control plan. • The work zone complies with Caltrans requirements. • Flaggers do not hold the traffic for extended periods of time. • Signs are removed or covered when they no long apply.

PROJECT INSPECTION RESPONSIBILITIES	
INJECTION PATCHING	• Does the operator have the correct safety equipment? • Is the weather going to be fair and above freezing for at least 48 hours after patching? • Is the aggregate and emulsion within specification? • Is there enough emulsion and aggregate available? Is the aggregate clean and dry and within specification? • Are the holes to be patched in a stable pavement? Are they dry? • Do the holes have vertical and clean sides? • Is the tack coat applied evenly and at an appropriate rate? • Does the aggregate flow evenly into the hole? • Does the emulsion evenly coat the aggregate? • Is the hole finished with a layer of aggregate? • Does the mixture show signs of curing (turn black) within the first 10 minutes? • Is the application stopped as soon as any problems are detected? • Does the application of the patching material appear uniform? • Does the surface have an even and uniform texture? • Check application rate based on amounts of aggregate and emulsion used. • What is the time between spreading and opening to traffic? • Adjust work time, emulsion level, or mixture temperature to allow opening to traffic.
COLD-MIX PATCHING: THROW AND GO	• Does the operator have the correct safety equipment? • Is the weather going to be fair and above freezing for at least 48 hours after patching? • Is the mix and tack emulsion within specification? • Is there enough emulsion and mixture available? Is the mixture workable at the temperatures of application? • Does the mix fill the holes evenly? • Are multiple lifts required, hole depth > 4 in (100 mm)? • Finished patches should be slightly crowned to allow for secondary compaction produced by traffic. • Does the mixture compact satisfactorily? • Is the surface finish even and uniform? • Do tires pick up the final surface? If so, dust with aggregate or sand.

PROJECT INSPECTION RESPONSIBILITIES	
COLD-MIX PATCHING: DIG OUTS AND EDGE REPAIRS	• Does the operator have the correct safety equipment? • Is the weather going to be fair and above freezing for at least 48 hours after patching? • Is the mix and tack emulsion within specification? • Is there enough emulsion and mixture available? Is the mixture workable at the temperatures anticipated during application? • Are the holes to be patched in clean, dry, and in a stable pavement? • For edge repairs, is the pavement edge clean and not spalled? • Is the tack coat sprayed evenly and at an appropriate rate? • Does the mix fill the holes evenly? • Are multiple lifts required, hole depth > 4 in (100mm)? • Finished patches should be slightly crowned to allow for secondary compaction produced by traffic. • Does the mixture compact satisfactorily? • Do the rollers allow a good surface profile? • Is the surface finish even and uniform? • Do tires pick up the final surface? If so, dust with aggregate or sand.
HMA PATCHING: THROW AND GO	• Does the operator have the correct safety equipment? • Is the weather going to be fair and above freezing for at least 48 hours after patching? • Is the mix and tack emulsion within specification? • Is there enough emulsion and mixture available? Is the mixture workable at the temperatures of application? • Are the holes to be patched in clean, dry, condition? Are they in a stable pavement? • Does the mix fill the holes evenly? • Are multiple lifts required, hole depth > 4 in (100 mm)? • Finished patches should be slightly crowned to allow for secondary traffic compaction. • Does the mixture compact satisfactorily? • Is the surface finish even and uniform? • Do tires pick up the final surface? If so, dust with aggregate or sand.

PROJECT INSPECTION RESPONSIBILITIES	
HMA PATCHING: DIG OUTS AND EDGE REPAIRS	• Does the operator have the correct safety equipment? • Is the weather going to be fair and above freezing for at least 48 hours after patching? • Is the mix and tack emulsion within specification? • Is there enough emulsion and mixture available? Is the mixture workable at the temperatures of application? Is the mix hot enough? • Where a pothole-patching machine is being used does it keep the mix hot without degrading it? • Are the holes to be patched in clean, dry condition? Are they in a stable pavement? • For edge repairs and dig outs are the edges straight and not spalled? • Is the tack coat sprayed evenly and no more than 0.04 in (1 mm) thick? • Does the mix fill the holes evenly? • Are multiple lifts required, hole depth > 4 in (100 mm)? • Finished patches should be slightly crowned to allow for secondary compaction produced by traffic. • Does the mixture compact satisfactorily? • Is the surface finish even and uniform? • Do tires pick up the final surface? If so, dust with aggregate or sand.
SKIN PATCHING	• Does the operator have the correct safety equipment? • Is the weather going to be fair and above freezing for at least 48 hours after patching? • Is the emulsion within specification? • Is the aggregate clean and dry and within specification? • Is there enough emulsion and aggregate available? • Are the holes to be patched in clean, dry condition? Are they in a stable pavement? • Is the emulsion sprayed evenly and no more than 0.04 to 0.08 in (1 to 2 mm) thick? • Is the aggregate spread evenly over the road surface? • Is the surface finish even and uniform? • Do tires pick up the final surface? If so, dust with aggregate or sand.
ROLLING: (WHEN REQUIRED)	• Is the patch stable before rolling begins? • Is the entire surface rolled only once? • Do the rollers travel slowly—5 mph (8 kph) maximum. Do they pick up or tear the mat? • Joints and overlaps may require extra passes in parking lot work especially.

PROJECT INSPECTION RESPONSIBILITIES	
CRACK SEALING	• Crack seal all seams • Fog seal patch surface
OPENING THE PATCHING TO TRAFFIC	• The traffic travels slowly—25 mph (40 kph) or less—over the fresh patches. • Reduced speed limit signs should be used when pilot cars are not used. • Remove all construction related signs when opening to normal traffic.
CLEAN UP	• All loose patching material should be removed from the travel way. • Remove binder application or spills from all areas including curbs, sidewalks and radius applications.

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CHAPTER 6 FOG AND REJUVENATING SEALS

6.1 OVERVIEW

Fog and rejuvenating seals are two of many pavement preservation strategies used to defer surface degradation and extend pavement surface life. The primary purpose of using a fog seal is to seal the road surface and defer surface degradation. The primary purpose of using rejuvenating seal is to soften the stiffness of the oxidized asphalt concrete (AC) pavement surface and to extend the life of the pavement surface by adjusting properties of the AC mixture. Some rejuvenators contain asphalt which also seals the surface in addition to adjusting the properties of the AC mixture.

6.1.1 Fog Seal

Fog seals are a mixture of asphalt emulsion and water applied to the asphalt surface of a road, street or highway. The Asphalt Emulsion Manufacturers Association (AEMA) defines a fog seal as "a light spray application of dilute asphalt emulsion used primarily to seal an existing asphalt surface to reduce raveling and enrich dry and weathered surfaces" (Asphalt Institute, 1999b). Others refer to fog seals as enrichment treatments or rejuvenators since they may add fresh asphalt, other additives or combination of asphalt and additives to an aged surface and lengthen the pavement surface life (Booth, 1988). Asphalt emulsion fog seals are also useful in chip seal applications to hold chips in place in fresh seal coats. These are referred to as flush coats in California. This can help prevent vehicle damage arising from flying chips. The Asphalt Institute also adds that fog seals can seal small cracks (Asphalt Institute, 1999a).

Fog seals are a method of adding asphalt to an existing pavement surface to improve sealing or waterproofing, prevent further stone loss by holding aggregate in place, or simply improve the surface appearance. For the seals to be effective, they must penetrate into the existing asphalt concrete surface. However, inappropriate use can result in slick pavements and tracking of excess material.

6.1.2 Rejuvenating Seal

Rejuvenating seals are a combination of various chemicals or a mixture of asphalt emulsion and recycling agents applied to the asphalt pavement surface. There are a variety of rejuvenating seals used in California. Rejuvenating emulsions (e.g. Reclamite (oil emulsion), PASS (asphalt, oil and additives) and Topein C (asphalt, oil and additives)) have additives (Malteens) that soften the existing binder, thus reducing its viscosity. These also improve the flexibility of the binder, which reduces the likelihood of cohesive failure. This may be beneficial in situations where the surface has an open texture and the existing binder is brittle from age. As with conventional emulsions, if these types of emulsion do not penetrate the surface, they may create a slippery surface after they break. Therefore, for the seals to be effective, they must penetrate into the existing asphalt concrete surface.

6.2 PROJECT SELECTION

6.2.1 Fog Seal

General Considerations

The original use of the fog seal was from the Asphalt Institute around 30 years ago. A diluted SS-1 asphalt emulsion was placed each day on new AC paving on the Pacific Coast highways due to the fact when the fog rolled in each evening, the paving contractor would experience raveling of the newly placed asphalt on curves. When there was no fog, there was no damage from traffic. Suspecting that the moisture penetrated the still warm AC causing this raveling, the contractor decided to seal out this moisture with the SS-1. It worked.

Fog seals are used as a method of enrichment of a pavement surface and as a method of holding stone in place. Thus, they are suitable to treat raveled and aged pavements. There is, at the present time, no simple way of quantifying the degree of aging in a pavement other than by visual inspection. Pavement will age at different rates due to mixture's properties, traffic applications, and environment effect. Some modified asphalts such as asphalt rubber and polymer modified asphalts will age at a slower rate than conventional binders. Fog seals will not correct distresses such as cracking, base failures, excessive stone already lost, or any other severe pavement defects. The experience of individual districts is key to determination of treatment timing.

On the traveled way, fog seals should only be used where surface penetration of the emulsion can be expected; that is, aged and raveled hot mix surfaces, chip-sealed surfaces, and open graded asphalt surfaces. On shoulders, gores, or dikes, penetration is desirable, but it is not essential. Fog seals darken the pavement surface and create distinct demarcation in these regions.

In general, traffic level is not a determining factor except in job set up. For situations requiring that the sealed pavement be opened to traffic shortly after the application of the seal, a blotter coat of sand may be used to prevent pick-up. Fog seal used on the traveled way should generally be limited to only those locations having an open surface texture. This includes chip seals, heavily aged dense graded and open graded. However, the seal may fill voids and reduce or eliminate the drainage function of Open-Graded Friction Coarse (OGFC). Figure 6-1 shows a typical fog seal application, while Figures 6-2 through 6-4 shows a range of suitable and unsuitable surfaces for fog seal project selection. The results of good fog seal applications are shown in Figures 6-5 and 6-6. It is important to always check the application rate and ensure that the emulsion has been diluted correctly.

Figure 6-1 Fog Seal Application

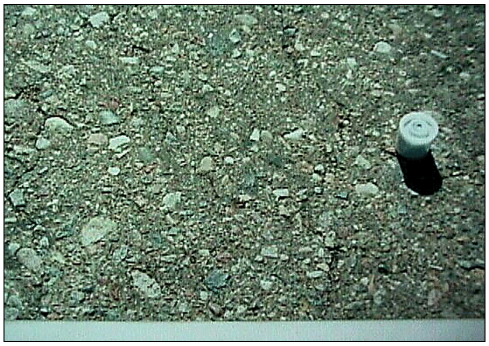

Figure 6-2 Suitable Surface, Heavily Aged Dense Graded HMA

Figure 6-3 Unsuitable Surface, Dense Graded HMA With Closed Surface

Figure 6-4 Suitable Surface, Open Graded HMA

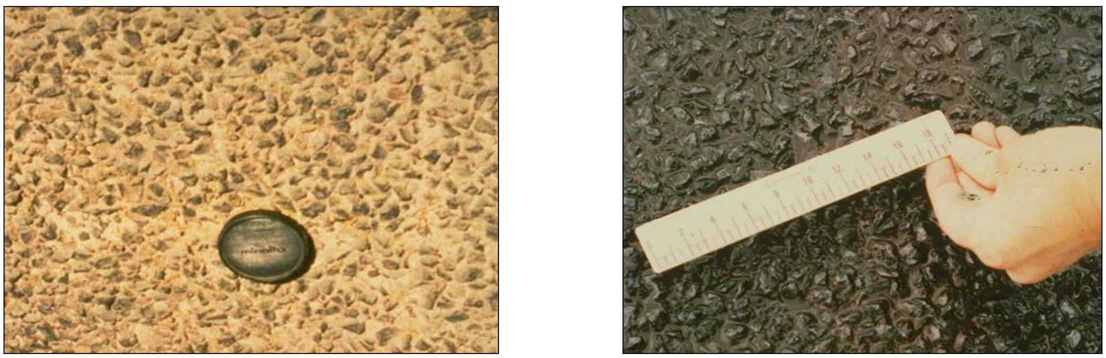

Figure 6-5 Chip Seal Before and After Fog Seal

a) Before Treatment b) After Treatment

Figure 6-6 Suitable Surface, Open Texture Dense Graded HMA

Fog seals (with sand blotter coats) may be used as a pavement maintenance treatment on lower speed roads or low traffic volume roads and shoulders. This protects the hot mix asphalt or chip seal surface. In some instances (where traffic is straight), a fog seal with a blotter coat may also be acceptable. The sand will generally be removed by the traffic leaving a good surface texture.

Flush coats (fog seals with light sanding) are used as a construction seal for new chip seals to lock the chips in place. This reduces vehicle/windshield damage due to flying chips when traffic is allowed on the new seal. These fog seals with sand blotter coats may also be used as a pavement maintenance treatment on lower speed roads or low traffic volume roads. This protects the hot mix asphalt or chip seal surface.

Fog seals are also suitable for sealing new shoulders, gores, or dikes. During construction on milled or ground HMA surfaces, fog seals may be used to keep dust down and prevent rock loss before the next surface is placed.

Fog seals may be used to protect a hot-mix asphalt (HMA) surface that is not aged significantly (i.e., within 1-2 years of placement after a major rehabilitation or maintenance treatment). This creates a layer of asphalt that seals surface voids and prevents air and water ingress. Fog seal may also be applied to a pavement that is showing severe raveling resulting from an oil shortage in the mix.

Benefits and Limitations

Fog seals are an inexpensive way of arresting raveling and adding binder back into aged surfaces. They can also hold chips in place in fresh chip seals, (or older chip seals beginning to loose rock) reducing the potential for vehicle damage.

Fog seals are not useful as seal coats on tight surfaces without the addition of aggregates as they will reduce surface texture and may create a slippery surface. If the skid number of the existing pavement is already low, the project is not appropriate for fog seal. Fog seals should not be used on Rubberized Asphalt Concrete (RAC) or polymer modified mixes unless the pavements are over five years old as these binders age at a different rate.

The application of fog seals is also limited by weather. Rain is a factor affecting cure; therefore fog seal should not be used when rains. The emulsion should be fully cured before freezing conditions are encountered. In addition, seal coats applied in the winter have less time to penetrate the pavement and are more prone to cause slick surface conditions.

Summary

In summary, the following guidelines should be considered when selecting a fog seal project:

- Pavement Surface Condition – Dry mixes, high air voids, and surfaces showing minor and/or moderate raveling. Fog seal can also be used on chip seals to prevent aggregate loss.
- Pavement Age – relatively newer pavement (not more than 2 years in service)
- Pavement Surface Mix – can be used on dense, gap, and open-graded mixes; however, the seal must penetrate.

6.2.2 Rejuvenating Seal

General Considerations

All asphalts harden as they age, primarily due to oxidation, volatile loss and other aging mechanisms (Barth, 1962). Hardening of an asphalt film takes place at different rates according to the access of air and temperature conditions in the pavement. Permeable pavements or pavements with high void contents can therefore age faster. Water ingress can also carry dissolved oxygen and trace elements that may promote aging. This means that pavements with open surfaces tend to age faster than those with closed surfaces. However, if modified binders are used in chip seal applications (e.g., asphalt rubber, polymer modified asphalt), the thicker films created by the higher binder content reduce the rate of aging.

Aging results in a binder that is more brittle. These binders eventually experience cohesive binder failures under traffic loads and stone loss or raveling. In some cases, the asphalt produces oxidized compounds that are acidic and bond well to the aggregate; however, these compounds may also react with water causing adhesive failure or stripping.

Benefits and Limitations

Rejuvenating seal is one way to soften the hardness of oxidized asphalt concrete surface, making it less brittle. The major benefit of the rejuvenating seals is to improve the flexibility of the asphalt binder and slow down the rate of aging and oxidization.

Rejuvenating seals may not be appropriate for using on rubberized asphalt concrete or polymer modified mixes. Rejuvenating seals may low the frictional proper of the existing pavement surface immediately after the application of the seals. If the skid number of the existing pavement is already low, the project is not appropriate for rejuvenating seal. The use of rejuvenating seals may also be limited by the weather condition.

Summary

In summary, the following guidelines should be considered when selecting a rejuvenating seal project:

- Pavement Surface Condition – old and fairly oxidized surface or surface starting to oxidize or show raveling. In addition to oxidation a pavement surface may begin to show evidence of distress cracking; if this is the case a rejuvenating scrub seal should be used. A rejuvenating scrub seal is the application of a rejuvenating emulsion followed by the application of aggregate.
- Pavement Age – generally used on pavement over 2 years or more.
- Pavement Surface Mix – Can be used on dense-, gap- and open-graded mixes; however, the seal must penetrate.

6.3 MATERIALS

6.3.1 General Terminology

Essential emulsion terminologies used for fog and rejuvenating seals are defined below:

- **Original Emulsion** – A mixture of asphalt cement and water that contains a small amount of emulsifying agent. Original slow-setting grade emulsions contain up to 43 percent water and original rapid setting grad
- **Diluted Emulsion** – An original emulsion that has been diluted by adding an amount of water equal to or more than the total volume of original emulsions contain up to 45 percent water.
- **Residual Asphalt Content** – The amount of asphalt remaining on the pavement surface after the emulsion has broken and cured (after all water has evaporated).

6.3.2 Materials and Specifications

The materials used in fog seals are usually asphalt emulsion and water. These products are covered by SSP-37-050. Rejuvenators may be used to soften and revitalize the aged binder in the pavement. Rejuvenation treatments require special attention in design and application and are covered in NSSP 37-600.

The emulsion types recommended for fog seals may be cationic (i.e., a positive surface charge on the asphalt particles), or anionic (i.e., a negative surface charge on the asphalt particles). The primary types used are CSS-1h and SS-1h. In some circumstances, CQS-1h (and LMCQS-1h) will give a faster set.

Note that asphalt emulsions of this type contain up to 43% water. However, any dilution referred to is *additional* water added to the emulsion. Residual asphalt is the binder left after *all* water (i.e., any added water and the original emulsion water) has evaporated.

Rejuvenating emulsions may take several forms and should be used on pavement showing age related distress associated with stiffening of existing binder. Generally this will take place after the first three years of service. They may be emulsions of exclusive rejuvenating additives and may include asphalt, polymer latex, and other additives. These are defined in manufacturer's literature and are covered by NSSP 37-600.

6.3.3 Design Considerations

Fog seals are designed based on the existing pavement surface condition. The design objective is to determine the application rate and sometimes dilution rate. The actual application rates may vary during the construction.

6.4 CONSTRUCTION

The majority of this section is focused on the construction of fog seal; however, some parts, such as surface preparation and traffic control would also applicable to rejuvenating seal jobs. Construction of rejuvenating seals should follow the manufacture's guidelines and recommendations to achieve desired end products.

6.4.1 General Description

A fog seal is designed to coat, protect, and/or rejuvenate the existing asphalt binder. The addition of asphalt will also improve the waterproofing of the surface and reduce its aging susceptibility by lowering permeability to water and air. To achieve this, the fog seal material (emulsion) must fill the voids in the surface of the pavement. Therefore, during its application it must have sufficiently low viscosity so as to not break before it penetrates the surface voids of the pavement. This can be accomplished by using either a slow setting or a quick setting emulsion that is diluted with water. Emulsions that are not adequately diluted with water may not properly penetrate the surface voids resulting in excess asphalt on the surface of the pavement after the emulsion breaks, which can result in a slippery surface. Figure 6-7 conceptually shows a fog seal application.

During application, the emulsion wets the surface of the aggregate and the existing binder film. Cationic (positively charged) emulsions can displace water from the surface of an aggregate or aged asphalt film. The emulsion then breaks by loss of water and chemical action, forming a film of new binder on the aggregate and existing binder film. The rate at which the emulsion breaks is dependent on several factors with weather conditions (e.g., wind, rain, temperature, etc.) being dominant factors. For anionic (negatively charged) emulsions, there is no surface specific interaction with most aggregates. The emulsion breaks due to water loss by evaporation and absorption of water by the aggregates and surface voids of the pavement.

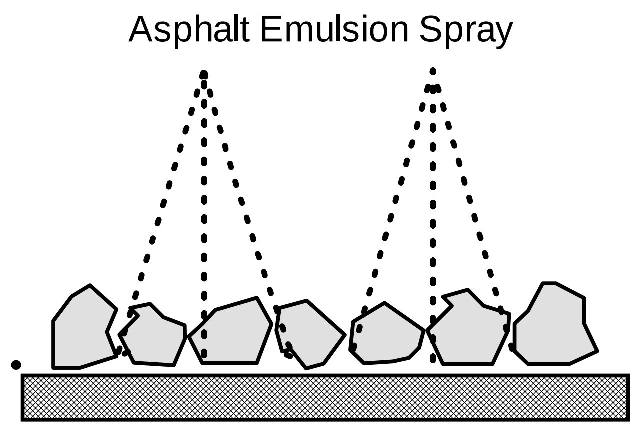

Figure 6-7 Schematic of Fog Seal Application (Hicks, 2002)

6.4.2 Site Conditions

To be effective, fog seals need to break quickly (process of evaporation of water begins; the emulsion turns black from brown) and cure completely (lose water to form a cohesive and non tacky film). This should be at a rate that allows traffic to be accommodated without the binder being picked up by vehicle tires. To achieve this behavior, the film forming properties of the binder must be adequate (i.e., the binder must be able to coalesce into a continuous film prior to allowing traffic on the new seal). Most asphalt films do not form well at low temperatures in the absence of low viscosity diluents. There are some rejuvenators that can be placed with ambient temperature down to 40^{o} F. The manufactures information should be researched. In most cases warm conditions with little to no chance of rain are necessary to ensure successful applications. Unless otherwise specified fog seals should not to be applied when the atmospheric temperature is below 50°F (10°C), and pavement temperature below 59°F (15°C).

If unexpected rain occurs, prior to the emulsion breaking, the emulsion may wash out of the pores of the pavement and break on the surface of the pavement creating a slippery surface.

6.4.3 Surface Preparation

Immediately before applying a fog seal, the pavement surface must be cleaned with a road sweeper, power broom, or flushed with a water pump-unit to remove dust, dirt, and debris. The pavement surface must be clean and dry before applying the fog seal. If flushing is required, it should be completed 24 hours prior to the application of the fog seal to allow for adequate drying.

6.4.4 Materials Preparation

Asphalt emulsions (original emulsions) contain up to 43% water, but must be diluted further before use. This additional dilution reduces viscosity (Figure 6-8) and allows the application of small amounts of residual binder to be adequately controlled. Generally, the supplier will dilute the original emulsion, in the field or at the plant. A dilution rate of 50% (1:1) (equal parts water to equal parts emulsion) is recommended in SSP 37-050 and NSSP 37-600. Dilution water must be portable and free from detectable solids or incompatible soluble salts (hard water).

This is the "normal" rate of dilution, but not always the best. During cooler conditions, on steep grades, tight asphalt surfaces, etc., it will be difficult to hold a .10 application of diluted seal coat on the surface. In order to get the (normally desired optimum).03 - .035 residual asphalt on these conditions, it sometimes takes a .08 application of 60/40 or .07 at 70/30 ratio. Using these guidelines, a less experienced user will just cut the application rate without changing the dilution rate, sacrificing the performance of the seal by reducing the residual asphalt. The dilution rate should be set by the Resident Engineer. Dilution water must be potable and free from detectable solids or incompatible soluble salts (hard water).

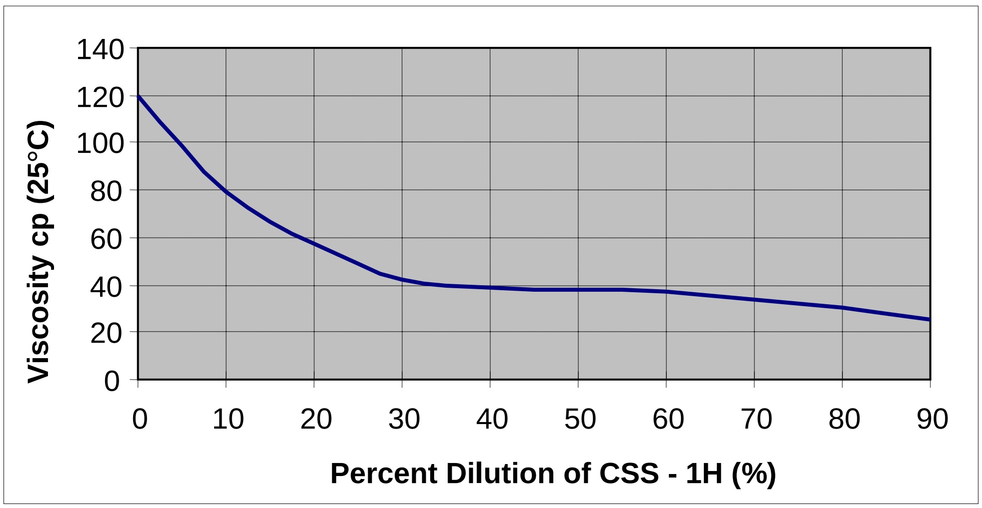

Figure 6-8 Viscosity Change with Dilution (Hicks, 2002)

Water can be checked for compatibility with the emulsion by mixing a small amount of the emulsion in a can (approximately 0.26 gal [1 liter]). The materials are mixed for 2 to 3 minutes with a stirrer and the resulting mixture is poured through a pre-wetted No. 100 (150 µm) sieve. If more than 1% by weight of material is retained on the sieve, the water is not compatible and clogging in spray jets may result. This test is illustrated in Figure 6-9.

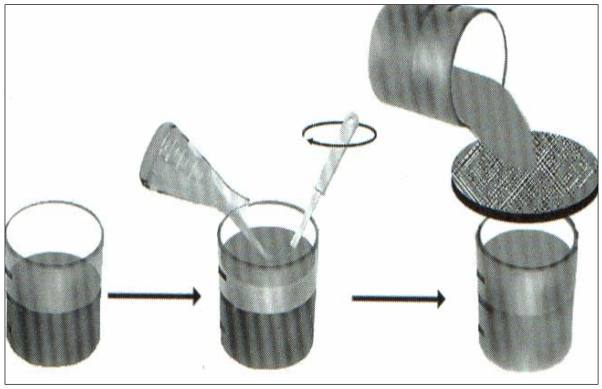

Figure 6-9 Simple Water Compatibility Test Method (Asphalt Institute, 1999a)

Incompatible water may be treated with 0.5 to 1.0% of a compatible emulsifier solution (the emulsion manufacturer can provide advice regarding compatible solutions). The emulsifier solution should be added to the water tanker and circulated for 10 to 15 minutes via pump before adding to the emulsion. If a water treatment is used, the compatibility test should be repeated using the treated water to ensure compatibility.

The emulsion should be diluted no more than 24 hours before its intended use (AEMA, 1990). This is to avoid settlement of the diluted emulsion. Water is always added to the emulsion and not the other way around. The emulsion may be circulated using a centrifugal or other suitable pump to ensure uniformity (AEMA, 1990).

6.4.5 Application Rates and Spraying

Properly calibrated distributor trucks shall be used to apply the emulsion (see Figure 6-2). Spray nozzles with 1/8” to 3/16” (4 to 5 mm) openings are recommended (AEMA, 1990). The emulsion may be heated to 122 °F (50°C) maximum, although, generally the emulsion is sprayed at ambient temperature (AEMA, 1990). The emulsion is sprayed at a rate that is dependant on the surface conditions (see Table 6-1). A test section representative of the entire surface should be chosen to approximate application rates (see Section 4.5). Typical application rates for diluted emulsion (1:1) range from 0.03 to 0.12 gal/yd^2 (0.15 to 1.0 l/m^2) depending on the surface conditions (Hicks, 2002). A 1:1 diluted emulsion is an original emulsion that has been subsequently diluted with equal parts water. Table 6-1 outlines the typical application rates for varying surface types and degree of dilution.

Table 6-1 Typical Application Rates

% ORIGINAL EMULSION	DILUTION RATE	TIGHT SURFACE* (gal/yd^2)	OPEN SURFACE** (gal/yd^2)
100	0	0.01 – 0.03	0.03 – 0.05
50	1:1	0.03 – 0.11	0.09 – 0.22
40	1.5:1	0.04 – 0.12	0.11 – 0.29

* *A tight surface is of low absorbance and relatively smooth (AEMA, 1990).*
** *An open surface is relatively porous and absorbent with open voids (AEMA, 1990).*

Ideally, one-half of the application should be sprayed in each direction to prevent build up on one side of stones only (this is particularly important in the case of chip seals) and rough surfaces. Build up on one side can result in a slippery surface and inadequate binder to fully enrich the surface or hold the stone.

6.4.6 Estimating Application Rates

To estimate the application rate, the RE shall take a one-liter can of diluted emulsion (usually 1:1 dilution rate) and pour evenly over an area of 1.2 yd^2 (1 m^2). This represents a diluted application rate of 1.2 yd^2 (1 m^2). If the emulsion is not absorbed into the surface after 2-3 minutes, decrease the application rate of the emulsion and apply to a new 1.2 yd^2 (1 m^2) area and repeat until the approximate application rate is found. If, after the first test, the surface looks like it can absorb more emulsion, increase the application rate of the emulsion and spread it over a new 1.2 yd^2 (1 m^2) area. Repeat until the approximate application rate is found. This same procedure can be followed using gallons and square yards to determine application rate.

6.4.7 Traffic Control

Traffic control should be in place before work forces and equipment enters onto the roadway or into the work zone. Traffic control is required both for the safety of the traveling public and the personnel performing the work. Traffic control includes construction signs, construction cones and/or barricades, flag personnel, and pilot cars to direct traffic clear of the construction operation. For detailed traffic control requirements, refer to the Caltrans project specifications and the Caltrans Code of Safe Operating Practices.

Traffic control is also required to protect the integrity of the application. The curing time for the fog seal material will vary depending on the pavement surface conditions and the weather conditions at the time of application. Under ideal conditions, including increasing air and surface temperatures, it is suggested that traffic be kept off the fog seal material for at least two hours and acceptable skid test (CT 342) values are achieved.

6.4.8 Safety (Personal Protection Equipment)

All employees are advised to wear and use the safety gear required for a fog seal operation. This includes, but is not limited to, items such as hard hats, approved Caltrans shirts, safety vests, earplugs, gloves, and safety glasses (Caltrans 1999b).

6.4.9 Quality control

Quality control and workmanship are critical to the performance and life of a fog seal treatment. There must be a cooperative effort between the Caltrans representative and the contractor's representative to conduct inspections of all project equipment before and during the project. The primary pieces of equipment for a fog seal operation are the boot truck/equipment and distributor bar. It is critical that each is functioning as required by the project specifications. The spray bar must be set to the appropriate height (distance) from the pavement surface and the nozzles must be set at the proper angle to assure a uniform application of material (Asphalt Institute, 1999b). The material temperatures should also be measured for quality control purposes.

The emulsion must be certified to specification according to established sampling and testing procedures (Caltrans, 1999a). Excess emulsion can create slick pavements.

It is recommended that project inspections be conducted so that any deficiencies in workmanship or materials are addressed and corrected. This process will also assist the department in identifying the performance of various fog seal materials; how they are performing on various surface conditions and how they are performing in various climatic zones.

6.4.10 Post Treatment

Sand blotters may be used, at approximately 0.20 lb/ft^2 (1 kg/m^2), to allow early opening to traffic. Sweeping may be required. The Resident Engineer or district maintenance personnel should assess this after application and opening to traffic. Even with sand cover, traffic control may be required to keep speeds down.

Skid resistance (coefficient of friction) can be measured using CT 342 or a Caltrans approved test. It is recommended that this be done after the application has cured to ensure the proper value is measured. The final surface shall yield a coefficient of friction not less than 0.30 as determine by CT 342 or a Caltrans approved test. To insure success, it is recommended that the coefficient of friction also be measured prior to any fog seal application. An estimate of 10% drop in the coefficient of friction can be expected after treatment.

A treated pavement shall not be opened to traffic until an acceptable value is recorded. If a treated pavement does not produce an acceptable coefficient of friction, see Table 6-2 for corrective action. Permeability may be monitored by CT 341 to ensure that an effective seal has been achieved. This should be done at the discretion of the Resident Engineer.

Table 6-2 Trouble Shooting Fog Seal Problems

CAUSE	SLICK SURFACE	NOT BREAKING	WASHES OFF	TACKY PICKS UP	WILL NOT DILUTE	BREAKS TOO FAST	DILUTION WRONG
Road Wet	•	•	•				
Road Too Dry				•		•	
Road Dusty				•		•	
Hard Water					Anionic		
Alkaline Water					Cationic		
Acidic Water					Anionic		
Application Too High	•	•	•	•			•
Application Too Low						•	•
Wrong Emulsion		•	•	•	•	•	
Rain	•	•	•				
Cold Weather	•	•					
Hot Weather				•		•	

6.5 TROUBLESHOOTING AND FIELD CONSIDERATIONS

6.5.1 Troubleshooting Guide

This section provides information to assist maintenance personnel in troubleshooting problems with fog seals, along with "dos and don'ts" that address common problems that may be encountered during the course of a project.

The troubleshooting guide presented in Table 6-2 associates common problems to their potential causes. For example, a slick surface may be caused by wet pavement, a high application rate, or rain. Cold weather could also contribute to slick pavements as the emulsion break may be delayed. The emulsion will be tacky and pickup if the existing road surface is dry or dusty, or the wrong emulsion is used.

In addition to the troubleshooting guide, Table 6-3 lists some application problems and their recommended solutions.

Table 6-3 Common Problems and Related Solutions

PROBLEM	SOLUTION
Spattering of the Emulsion	• Reduce the rate of dilution. • Ensure the spray bar height is set correctly. • Ensure the spray pressure is not set too high.
Streaking of the Emulsion	• Ensure the emulsion is not too cold. • Ensure the emulsion viscosity is not too high. • Ensure the nozzles are at the same angle. • Ensure the spray bar is not too high or too low. • Ensure the spray bar pressure is not too high. • Ensure not all nozzles are plugged.
Bleeding or Flushing of the Emulsion	• Ensure the emulsion application rate is not too high. • Check application and dilution rate and recalibrate sprayer, if necessary.
Surface Coefficient of Friction is too Low per CT 342	• Apply coating of clean dry sand. • Sweep sand with rotary broom to absorb excess binder. • Perform CT 342. • Repeat process until coefficient of friction is at least 0.30.

**Do not open treated surface until coefficient of friction is at least 0.30 as determined by CT 342.*

6.5.2 Dos and Don'ts

The following list provides a quick reference to avoid making common mistakes with fog seals.

Do check water compatibility before dilution.
Do check dilution - has it been done, by whom, and when?
Do ensure that there is no contamination of the base emulsion by water, oils, or other liquids.
Do prevent contamination by other emulsions.
Do protect emulsions from freezing or localized boiling due to the application of direct heat.
Do heat emulsion gently and ensure heating coils are under the liquid level (max 122°F (50°C)).
Do load from the bottom of tankers or sprayers to avoid foaming.
Do check equipment and nozzles.
Do check application rates.
Do exercise proper traffic control.
Do ensure the know-how is available on the job.
Do add water to emulsion, not emulsion to water.
Do not store diluted emulsion longer than 24 hours.
Do not continuously stir or circulate emulsion.
Do not apply emulsion if air temperature is < 50°F (10°C) and pavement temperature < 60°F (15°C).
Do not apply emulsion if rain or cool temperatures are imminent.
Do not continue application if adequate breaking period is not available.
Do not open treated surface to traffic until coefficient of friction is at least 0.30 as determined by CT 342.

6.5.3 Field Considerations

The following field considerations are a guide through the important aspects of performing a fog-sealing project. The various tables contain items that should be considered in order to promote a successful job outcome. Thorough answers to these questions should be determined, as required, before, during, and after application of fog seal. The appropriate staff to do this will vary by job type and size. Some topics may need attention from several staff members. The field personnel should be acquainted with its contents. The intent of the tables is not to form a report but to bring attention to important aspects and components of the project process. Some information is product specific and contained in the relevant standard specifications, standard special provisions, or special provisions.

PRELIMINARY RESPONSIBILITIES	
PROJECT REVIEW	• Is the project a good candidate for a fog seal? • What is the existing surface type? • Has an assessment been made of the surface absorption? • How much stone has been lost? • How much bleeding or flushing exists? • Review project for bid/plan quantities. • What is the relative cost?
DOCUMENT REVIEW	• Bid Specifications • Special Provisions • Emulsion Specifications • Traffic Control Plan (TCP) • Material Safety Data Sheets
MATERIALS CHECKS	• What is the type and dilution rate of the emulsion selection? • Is the emulsion is from an approved source (if required)? • Has the emulsion been sampled and submitted for testing (if required)? • The water to be used is compatible with the emulsion? • Is sand required? Is it within specification and dry? • Is the emulsion temperature within application temperature specification?
PRE-SEAL INSPECTION RESPONSIBILITIES	
SURFACE PREPARATION	• Is the surface clean and dry? • Have all pavement distresses been repaired? • Has the existing surface been inspected for drainage problems?

EQUIPMENT INSPECTION RESPONSIBILITIES	
BROOM	• Are the bristles the proper length? • Can the broom be adjusted vertically to avoid excess pressure on the surface?
SPRAY DISTRIBUTOR	• Is the spray bar at the proper height? • Are all nozzles uniformly angled at 15 to 30 degrees from the spray bar axis? • Are all nozzles free of clogs? • Is the spray pattern uniform and does it properly overlap (double or triple)? • Is the application pressure correct? • Is the distributor properly calibrated? • Is there a working and calibrated thermometer on site? • Has water been added to emulsion in correct proportion and circulated? • Is the application rate being monitored throughout the day/project?
SAND SPREADER	• Do the spreader gates function properly and are their settings correct? • Is the sand spreader's calibration uniform across the entire head? • Is the sand free flowing? • Are the truck hook-up hitches in good condition?
TRUCKS	• Is the truck box clean and free of debris and other materials? • Is the truck hook-up hitch in working order? • Is a truck box apron or extension required for loading the sand spreader?
ALL EQUIPMENT	• Is all equipment free of leaks? • Is all equipment calibrated and clean?
SITE CONSIDERATIONS	
TRAFFIC CONTROL	• Do the signs and devices used match the traffic control plan? • Does the work zone comply with Caltrans traffic control policies as laid out in the Caltrans Safety Manual? • Do flaggers not hold the traffic for extended periods of time? • Does the pilot car lead traffic slowly — 25 mph (40 kph) or less—over fresh sand blotted fog seals? If not sanded, allow at least 2 hours before opening to traffic. • Are unsafe conditions promptly reported to a supervisor (contractor or agency)? • Are signs removed or covered when they no long apply?

SITE CONSIDERATIONS	
WEATHER REQUIREMENTS	• Are minimum surface and air temperatures adhered to? • Are air and surface temperatures checked at the coolest location on the project? • Do air and surface temperatures meet agency requirements? • Are high winds expected during application of the fog seal? High winds can create problems with the diluted emulsion application. • Will the expected weather conditions delay the breaking of the emulsion? High temperatures, humidity, and wind will effect how long the emulsion takes to break. • Is the application of the fog seal discontinued if rain is likely?
BINDER CONSIDERATIONS	
BINDER APPLICATION	• Are the agency guidelines and requirements being followed? • Has a check been done on the absorption ability of surface? • Is the surface oxidized and porous? More oil can be applied to dried-out and porous surfaces. • Is the surface smooth, non-porous, or bleeding (asphalt rich)? Do not apply to smooth, non-porous, and asphalt-rich surfaces. • Is the traffic volume on the road high? Less oil must be applied on roads with high traffic volumes. • Does the emulsion soak into the surface? If not, application rate is too high. • Is the surface texture coarse? If so, spray should be applied in both directions to avoid build up on one side of stones. • Are manhole covers and drainage inlets covered to keep binder from entering water bodies?
CHECKING APPLICATION RATES	**Binder - Method A (Recommended for Calibration)** • The weight of a 1 yd^2 (0.84 m^2) carpet, pan or, non-woven geotextile material is recorded and placed on the road surface. • The distributor applies emulsion over the carpet, pan, or geotextile material. • The weight of the carpet and emulsion, pan and emulsion, or geotextile material and emulsion is recorded. • The weight of the carpet, pan, or geotextile material without emulsion is subtracted from the weight of the carpet, pan, or geotextile material with emulsion. • The weights applied to the area of carpet (i.e., lb/yd^2 or kg/m^2) must be converted to the units of the control mechanism, which is gal/yd^2 or l/m^2, through knowledge of the specific gravity of the emulsion. If the distributor is not spraying the binder at the correct application rate, adjustments must be made to the controls and the process described above repeated until the correct application rate is achieved. Although this is the responsibility of the contractor, the inspector should verify that the distributor is spraying the binder at the correct application rate.

BINDER CONSIDERATIONS

CHECKING APPLICATION RATES

Example – Checking Fog Seal Application Rate (Method A)

- Given:
  Applying a Fog Seal with a 1:1 diluted emulsion.
  Tight surface texture.
  Recommended application rate of 0.03 – 0.11 gal/yd^2 (see Table 6-1).
  Specific gravity of Emulsion (G_E) = 1.010.
  Unit Weight of Water (γ_W) = 62.4 lb/ft^3.
  Conversion Factor (C_{f1}) = 7.5 gal/ft^3.

Find the actual application rate ($W_{A'}$).

- Measure the weight of a 1 yd^2 carpet (W_C).
  (W_C) = 4.0 lb
- Measure the weight of 1 yd^2 carpet and applied emulsion (W_{C+E}).
  (W_{C+E}) = 4.7 lb
- Calculate the weight of emulsion covering the 1 yd^2 carpet (W_E).
  (W_E) = (W_{C+E} - W_C)
  (W_E) = (4.7 lb - 4.0 lb)
  (W_E) = 0.7 lb
- The application rate is the weight of emulsion applied per unit area (W_A).

$$(W_A) = \left(\frac{W_E}{1yd^2}\right)$$

$$(W_A) = \left(\frac{0.7lb}{1yd^2}\right)$$

$$(W_A) = 0.7\frac{lb}{yd^2}$$

Convert this application rate to gal/yd^2.

- Calculate the unit weight of the emulsion (γ_E) by multiplying the specific gravity of the emulsion (G_E) by the unit weight of water (γ_W).

$$(\gamma_E) = (G_E \times \gamma_w)$$

$$(\gamma_E) = \left(1.010 \times 62.4\frac{lb}{ft^3}\right)$$

$$(\gamma_E) = 63.024\frac{lb}{ft^3}$$

BINDER CONSIDERATIONS	
CHECKING APPLICATION RATES	***Example* – Checking Fog Seal Application Rate (Method A) (continued)** • Convert the unit weight of the emulsion (γ_E) to lb/gal (γ_{Elb}) by dividing (γ_E) by (C_{f1}). $(\gamma_{Elb}) = \left(\frac{\gamma_E}{C_{f1}}\right)$ $(\gamma_{Elb}) = \left(\frac{63.024 \frac{lb}{ft^3}}{7.5 \frac{gal}{ft^3}}\right)$ $(\gamma_{Elb}) = 8.4 \frac{lb}{gal}$ • Convert (W_A) in lb/yd^2 to ($W_{A'}$) in gal/yd^2 by dividing (W_A) by (γ_{Elb}). $(W_{A'}) = \left(\frac{W_E}{\gamma_{Elb}}\right)$ $(W_{A'}) = \left(\frac{0.7 \frac{lb}{yd^2}}{8.4 \frac{lb}{gal}}\right)$ $(W_{A'}) = 0.08 \frac{gal}{yd^2}$ Check this value against the recommended application rates given in Table 6-1. For the given surface condition and dilution rate this application rate is acceptable.

BINDER CONSIDERATIONS	
CHECKING APPLICATION RATES	**Binder – Method B (Recommended for Random Checks)** • Park the distributor on level ground and measure the number of liters or gallons of emulsion. • Measure off a known distance for a test section. • Have the distributor apply diluted emulsion to the test section. • Park the distributor on level ground and re-measure the number of liters or gallons of emulsion. • Make necessary adjustments to volume based on temperature corrections per Standard Specifications section 93-1.04. • Subtract the number liters or gallons after application from the original number of liters or gallons to obtain the number of liters or gallons applied. • Divide the number of liters or gallons applied by the number of square meters or square yards covered by emulsion to give the application rate in gal/yd^2 or l/m^2. • If the distributor is not spraying the binder at the correct application rate, adjustments must be made to the controls and the process described above repeated until the correct application rate is achieved. Although this is the responsibility of the contractor, the inspector should verify that the distributor is spraying the binder at the correct application rate throughout the project.

PROJECT INSPECTION RESPONSIBILITIES	
BINDER APPLICATION	• Is building paper used to start and stop emulsion application for straight edges? • Is the emulsion within the required application temperature range? • Does the application look uniform? • Are any nozzles plugged? • Is there streaking on the applied emulsion? • Are application rates randomly checked? • Is the speed of the distributor adjusted to match that of the sand spreader (if used) and to avoid start-and-stop operations? • Is the distributor stopped if any problems are observed?
TRUCK OPERATION	• Are the trucks staggered across the fresh fog seal coat to avoid driving over the same area? • Do the trucks travel slowly on the fresh seal? • Are stops and turns made gradually? • Do truck operators avoid driving over exposed oil?

PROJECT INSPECTION RESPONSIBILITIES	
OPENING A FOG SEAL TO TRAFFIC	• Are results from CT 342 at least 0.30? • Does traffic travel slowly — 25 mph (40 kph) or less—over the fresh seal until seal is broomed and opened to normal traffic? If not sanded, allow 2 hours before opening to traffic. • Are reduced speed limit signs used when pilot cars are not used? • Are pavement markings placed after brooming and before opening to normal traffic? • Are all construction related signs removed when opening to normal traffic?
CLEAN-UP	• Is all loose (excess) sand from brooming operation removed from travel way? • Are binder spills cleaned up?
REMOVAL OF EXCESS BINDER FROM SURFACE	
SAND APPLICATION	• Are enough aggregate trucks on hand to maintain a steady supply of sand to the spreader? • Is clean dry sand being used? • Does the sand application appear uniform? • Is sand used only once?
BROOMING	• Does brooming begin as soon as possible after sand is applied? • Is initial brooming done lightly with a rotary broom to distribute and set sand in surface? • Is secondary brooming done to remove loose sand coated with excess binder? • Is brooming process repeated until results from CT 342 at least 0.30?

6.6 REFERENCES

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CHAPTER 7 CHIP SEALS

7.1 OVERVIEW

Chip sealing is the application of a bituminous binder immediately followed by the application of an aggregate. The aggregate is then rolled to embed it into the binder. Multiple layers may be placed and various binder and aggregate types can be used to address specific distress modes or traffic situations.

7.1.1 Types of Chip Seals

There are several types of chip seals in use today. They include the following:

- **Single Chip Seal:** A single chip seal is an application of binder followed by an aggregate. This is used as a pavement preservation treatment and provides a new skid resistant wearing surface, arrests raveling, and seals minor cracks. Figure 7-1 illustrates a single chip seal application.

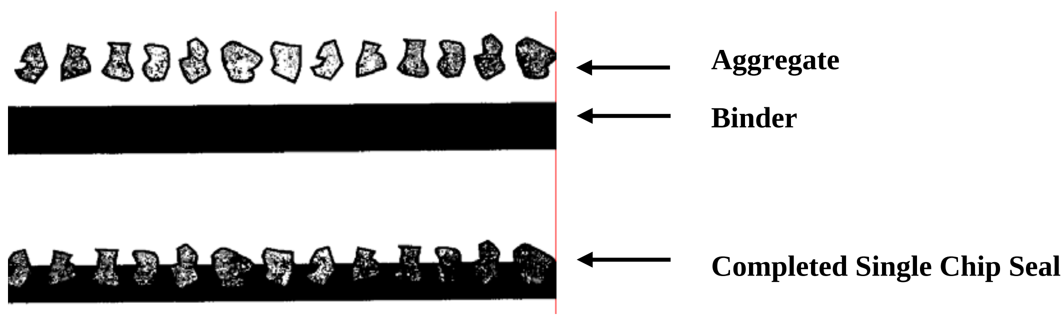


Figure 7-1 **Single Chip Seal**

- **Multiple Chip Seal:** A multiple chip seal (or armor coat) is a built-up seal coat consisting of multiple applications of binder and aggregate. As an example, a double chip seal consists of a spray application of binder, spreading a layer of aggregate, rolling the aggregate for embedment, applying an additional application of binder, spreading another layer of aggregate (approximately half the average least dimension of the base coat aggregate), and rolling once more. Sweeping should be done between applications. This process may be repeated, as necessary, to build up a pavement's edges. Multiple chip seals are used where a harder wearing and longer lasting surface treatment is needed. **Caltrans does not use multiple chip seals at this time.** Figure 7-2 illustrates a multiple chip seal application.

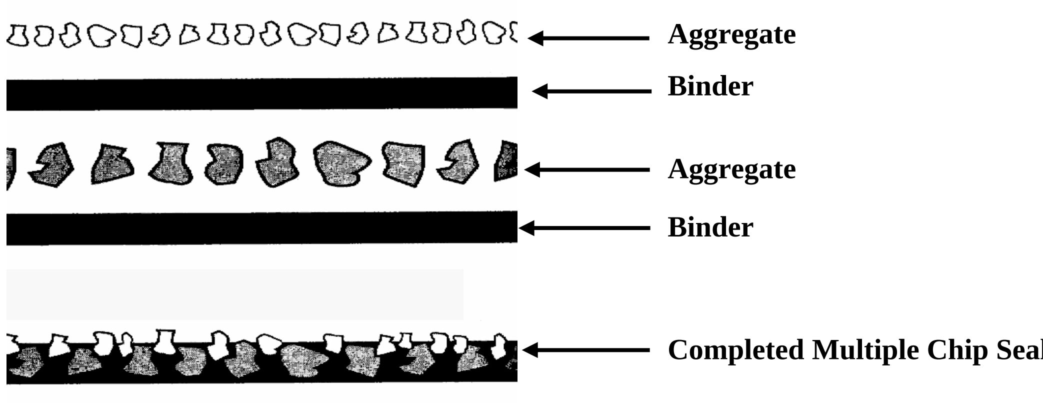


Figure 7-2 Multiple Chip Seal

- **Stress Absorbing Membrane (SAM) Seal:** A SAM is a single chip seal in which a modified binder (normally asphalt rubber) is applied, followed by a layer of aggregate, and rolling. Binder applications are much higher than those used for conventional chip seals. Generally a SAM has been referred to as being used with asphalt rubber (AR) binders.
- **Stress Absorbing Membrane Inter-layer (SAMI):** A SAMI is a membrane seal that is used to retard the rate of reflection cracking in new overlays. It consists of an application of modified binder followed by a layer of aggregate, spread and rolled. An overlay is then placed over the membrane. If necessary, traffic may be allowed to operate on the SAMI prior to construction of the overlay.
- **Scrub Seals:** A Scrub Seal is a more advanced and aggressive multi-step chip seal process that uses a specialized emulsion (PMRE) as the chip binder and rejuvenator in conjunction with a mechanized scrub broom that forces the optimum amount of emulsion into the cracks.
- **Other Interlayer Applications:** Interlayers, such as fabrics followed by a chip seal have also been used in California. These are discussed in more detail in Chapter 13.

7.1.2 Binder Types

Binder type varies according to the type of chip seal being used. Binder types include:

- **Asphalt Emulsion:** Asphalt emulsions shall be composed of a bituminous material uniformly emulsified with water and an emulsifying or stabilizing agent. Polymer modified asphalt emulsion shall also contain a polymer. Anionic and Cationic Emulsions and Polymer-modified emulsions (PME), such as PMCRS-2 and PMCRS-2h, are included in the Standard Specifications, Section 94 (Caltrans, 2006).
- **Performance Graded (PG) Asphalt:** California is divided into different climate zones based on different climatic conditions. PG asphalt binders are selected to meet expected climatic conditions as well as aging considerations with a certain level of reliability. Polymer modified binders are used wherever extra performance and durability are desired.
- **Asphalt Rubber Binder:** Binders modified with high levels of crumbed tire rubber and a high natural rubber content material. These binders are sprayed hot and require hot chips pre-coated with asphalt. Hot applied AR binders can be placed at cooler temperatures than emulsion binders and can be placed at night.

- **Rejuvenating Emulsion:** These are emulsions modified with rejuvenating oils (and sometimes polymers) that are used to penetrate and soften existing asphalt pavements. The emulsion is not only highly polymerized which adds flexibility, toughness and durability to a chip seal, but contains a recycling agent that rejuvenates the aged pavement surface. It also rejuvenates the aged surface of the walls of the cracks that have occurred through distress caused by aging; therefore significantly aids in the sealing of the cracks.

Table 7-1 lists common binder types and their suitable applications.

Table 7-1 Binder Type and Suitable Applications

BINDER TYPE	SINGLE	MULTIPLE	SAND	SAM/ SAMI
Asphalt Emulsions	Yes	Yes	Yes	No
PG graded asphalts	Yes	Yes	Yes	No
Asphalt Rubber	Yes	Yes	Yes	Yes
Rejuvenating Emulsions	Yes	Yes	Yes	No

7.2 PROJECT SELECTION

The general selection of preventive maintenance treatments was covered in Chapter 3. The selection of a pavement for a chip seal project is based on the structural soundness of a pavement and the types of distress that are present. The ability of a treatment to address the current condition of a project is paramount in selecting an appropriate treatment. The main criteria addressed by the varying chip seal types are:

- **Conventional chip seals** are used on structurally sound pavements with minimal cracking.
- **Polymer-Modified Emulsion (PME) chip seals** are used to correct raveling and pavement oxidation.
- **Rubberized chip seals** cure quickly, restore skid resistance on worn surfaces and resist reflection cracking.
- **Binders** such as asphalt rubber and polymer modified (PG) asphalts may be used to address specific distress modes.
- **Distresses such as cracking, flushing, and base failures** cannot be addressed with conventional or hot applied chip seals.
- **Deformation, rutting and shoving** cannot be addressed with chip seals of any kind.

Table 7-2 lists appropriate binder/chip seal combinations for addressing various distress mechanisms. Generally, chip seals are not used on roads with AADT > 40,000.

The main advantages associated with chip seals include:

- **Improved Skid Resistance**: Chip seals provide good skid resistance.

- **Cost Effective Treatments:** Chip seals are typically cost effective when properly placed on the right type of pavement.
- **Good Durability:** Chip seals wear well and can have long service lives.
- **Ease of Construction:** Chip seals are typically constructed rapidly and cause less disruption to the traveling public than do other treatments that take longer.

Table 7-2 Binder/Chip Seal Combinations for Addressing Specific Distress Mechanisms

Binder/ Chip Seal Combination	**Raveling**	**Aged Pavements**	**Bleeding/Flushing**	**Load Associated Cracks**	**Water Proofing**	**Climate Associated Cracks**	**Heavy Traffic Volumes**	**Stone Retention**	**Improve Skid Resistance**
PME/Single	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes
PME/Double	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes
PME/Sand	Yes	Yes	No	No	Yes	No	No (light)	Yes	No
PG/Single	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes
PG/Double	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PG/Sand	Yes	Yes	No	No	Yes	No	No	Yes	No
AR/SAM	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Rejuvenating Emulsion/single	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes

The main disadvantages associated with chip seals include:

- **Cure Time:** PME seals take several hours (depending on the climatic conditions) to reach a stage where they can tolerate unrestricted traffic.
- **Flying Chips:** Chip seals must be swept to remove excess stone to avoid broken windshields and vehicle damage.
- **Noise Considerations:** Chip seals can be noisy while traveling on.
- **Weather Considerations:** Cold applied chip seals must be constructed during warm, dry weather and during the daytime only. Hot applied chip seals may be applied in cooler conditions and at night.
- **Performance**: Chip Seals create a rougher surface and are generally not used for parking lots. Chip seals do not improve ride quality.

Limitations of chip seals include:

- **PME Seals:** These are not normally suitable for intersections or high stress areas.
- **PG and AR Seals:** These cure quickly, so the aggregate has to be applied quickly.

7.3 DESIGN AND SPECIFICATIONS

7.3.1 Material Specifications

Binders

Binders are selected based on their performance characteristics. They need to provide good adhesion and/or stickiness. The performance grading (PG) system is used to select binders based on the idea that asphalt binder properties should be related to its applied conditions including climatic conditions and aging conditions. A set of tests are evolved to measure physical properties of the binder that can be directly related to field performance of the pavement at extreme temperatures. For example, a binder identified as PG 64-10 must meet performance criteria at an average 7-day maximum pavement temperature of 64°C and also at a minimum pavement temperature of –10°C.

Polymer Modified emulsion binders usually contain latex additives, although other elastomeric polymers are often used. The purpose of the polymer is to improve stone retention during the early life of the treatment and to increase the softening point of the binder after cure (i.e., the temperature at which the binder changes phase from being primarily solid to being primarily fluid). The general-purpose base binder is an 85/100-penetration grade asphalt cement. This base binder mostly controls low temperature properties. For cold climates, a softer base asphalt (e.g. an 120/150 penetration grade) may be warranted. For hot climates, a harder base binder (e.g., a 40/50 penetration grade) might be considered. Emulsion specifications are included in Section 94 of the Standard Specifications (Caltrans, 2006) and related SSPs as discussed in Chapter 2 of this guide.

Aggregates

For chip seals, the best performance is obtained when the aggregate has the following characteristics:

- Single-Sized (if possible)
- Clean
- Free of Clay
- Cubical (limited flat and elongated particles)
- Crushed Aces
- Compatible with the Selected Binder Type
- Aggregates Must be Damp for Emulsion Use & Dry for Use with Hot Binders

The specifications for aggregates used in chip seals are included in Section 37-1.02 of the Standard Specifications.

7.3.2 Chip Seal Design

Properly designed chip seals have proven to be cost effective in sealing pavements and providing a new riding surface with enhanced frictional characteristics. Many countries have developed rational chip seal design methods and, as a result, have used chip seals on major highways. Caltrans does not currently employ a formal design process for Chip Seals. The methods currently used are based on experience and do not address adjustments for the factors identified below. **This section is included for information purposes only and to provide a foundation for an improved design process.**

The basics of chip seal design are straightforward, as the binder application rate and the aggregate application rate are the only variables of major importance to consider. However, to correctly calculate these rates requires an understanding of the materials and the surface on which they are to be applied. Additional factors to consider include traffic, climate, and existing surface condition. The determination of the proper binder and aggregate application rates is discussed in greater detail in the following two sections. The design of multiple seal coats is also briefly described. However, sand seals and sandwich seals are designed strictly from experience and are not included in this discussion of design procedures.

Binder Application

In chip seal design, the residual binder application rate is the most important factor affecting seal performance. Enough binder must be present to hold the aggregate in place, but not so much that the binder fills, or is forced by traffic action to cover the aggregate. The proper amount of binder ensures that the desired surface texture is maintained. Chip seal design is not like hot mix asphalt design, in that film thickness is not as applicable a concept. Binder application rates are determined based on the average least dimension of the aggregate, as well as other aggregate properties such as shape, density, absorption and grading. The optimum binder content also depends on how much binder flows into existing voids in the pavement, and how much binder is already present at or near the pavement surface.

The McLeod method is the most common design method for chip seals (McLeod, 1969); however it is not used by Caltrans. This method assumes that 70% of the voids in the aggregate must be filled (i.e., 70% embedment). In some states, this is adequate and has been adopted as the standard; however, modifications can be made for varying project conditions.

A more detailed discussion on this design method can be found in “A General Method of Design for Seal Coats and Surface Treatments” by N.W. McLeod. The McLeod method also assumes the use of a cubical, single-sized aggregate. This may not always be the case (e.g., California specifications specify graded aggregates). The main modification for graded aggregates is determining a median aggregate size (50% passing). The aggregate shape must also be examined; this is done by measuring the flakiness index (Jannisch, 1998). The average least dimension (ALD) can then be determined using the following equation (Jannisch, 1998):

$$H = [M / 1.139285 + (0.011506)*FI] \quad (7.1)$$

where: *H = Average Least Dimension, or (ALD)*
M = Median Particle Size
FI = Flakiness Index

ASTM C29 is used to measure the loose unit weight. This approximates the voids in the loose aggregate when it is dropped onto the pavement. The voids in this state are 50% for cubical, single-size aggregate and lower for graded aggregate. It is assumed that once rolled a cubical aggregate will reduce its unit weight to a point where the voids content is 30% and finally to 20% once trafficked. These assumptions are adjusted when using graded aggregates. Figures 7-3 through 7-5 illustrate the average least dimension (ALD) concept, along with the effects of flakiness and changes in voids based on compaction.

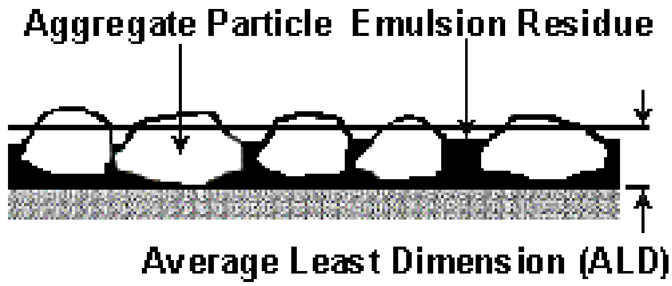


Figure 7-3 Illustration of ALD (FHWA, 1992)

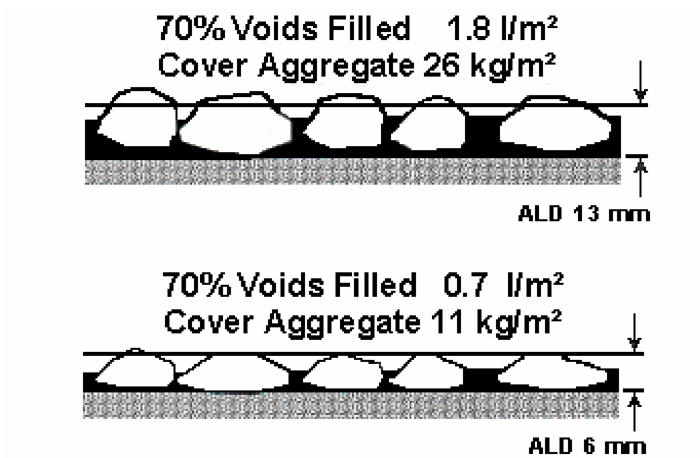


Figure 7-4 Illustration of Flakiness of Aggregates (FHWA, 1992)

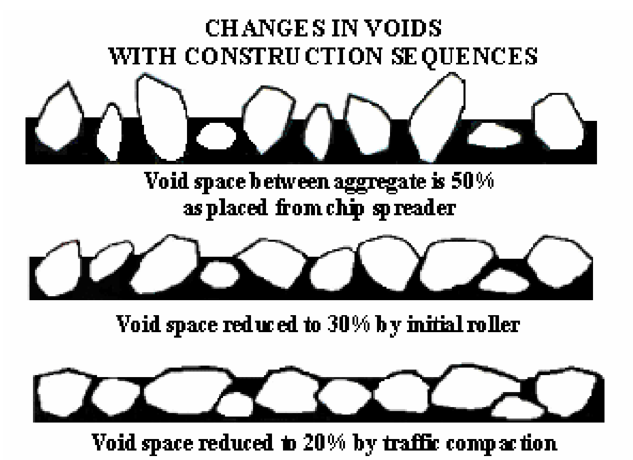


Figure 7-5 Effects of Compaction on Voids in Cubical Aggregate (FHWA, 1992)

The voids in loose aggregate may be calculated using the following equation (Jannisch, 1998):

$$V = 1 - W / 62.4*G \qquad (7.2)$$

where: *V = Voids in the Aggregate*
W = Loose Unit Weight of the Aggregate (in lbs/ft3])

G = Bulk Specific Gravity of the Aggregate (usually determined from local information or measured)

Most design methods calculate the specific requirements for each job by considering the required corrections in addition to the basic application rate (the rate designed to result in 70 percent embedment). One method for estimating the binder content is as follows (Jannisch, 1998):

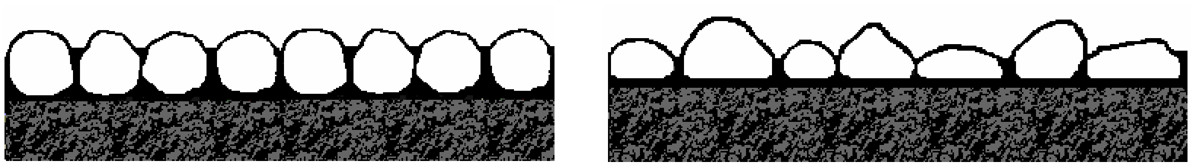
$$B = [2.244(H) \times T \times V + S + A + P] / R \ldots\ldots(7.3)$$

where: *B = Binder Content (g/yd2)*
H = ALD (inches) – (See Figure 7-3)
T = Traffic Factor – (See Table 7-3)
V = Voids in Loose Aggregate (%) – (See Equation 7.2)
S = Surface Condition Factor (g/yd2) – (See Table 7-5)
A = Aggregate Absorption (g/yd2) – (See CTM 303)
P = Surface Hardness Correction for Soft Pavement (g/yd2) – (See Table 7-6)
R = Percent Binder in the Emulsion (%) – (See Manufacturer)

For projects in areas maintained by snowplows, the binder content is calculated using both the median particle size and the ALD. The average of these two results is used as the starting application rate in these areas.

Corrections to the basic application rate for the aggregate address variables that affect the level to which it becomes embedded in the binder. The corrections are ultimately applied to the calculation of the binder application rate. These variables include:

- **Aggregate Characteristics:** Important aggregate characteristics include absorption and shape. Corrections for absorption are based on experience and the characteristics of the local aggregates. Chip shape effects are variable: rounded chips leave greater voids and do not interlock and are not recommended. This type of chip also requires additional binder. Non-uniform sized aggregates produce uneven surfaces. Figure 7-6 illustrates both rounded and non-uniform chip applications.



a) Rounded b) Non-Uniform

Figure 7-6 Aggregate Shape Characteristics (South Australian DOT, 1995)

- **Traffic Volume:** This factor accounts for the role that traffic volumes play in achieving the ultimate embedment of 80 percent (20 percent void space). The traffic factor is lower for higher traffic volumes and higher for lower traffic volumes. Table 7-3 lists the application rate correction factors associated with varying traffic levels

Table 7-3 Traffic Factors (Jannisch, 1998 and McLeod, 1969)

VEHICLES/DAY	0-100	101-500	501-1000	1001-2000	>2000
Correction Factor	0.85	0.75	0.70	0.65	0.60

- **Loss of Aggregate Due to Traffic (Traffic Whip-Off):** A traffic whip-off correction accounts for the effects of traffic operations on removing aggregates from newly chip sealed roads. Reasonable values for losses are 5% for low volume roads and residential streets and 10% for high-speed roads and highways. Table 7-4 lists road types and associated whip-off correction factors

Table 7-4 Road Type and Associated Aggregate Loss (Whip-Off) Factor

(Jannisch, 1998)

ROAD TYPE	PERCENT WASTAGE (%)	WHIP-OFF FACTOR (E)
Rural & Residential	5	1.05
Higher Volume Roads	10	1.10
State Highways	15	1.15

- **Existing Pavement Condition:** Existing pavement conditions play a very important role in determining the optimum binder content. A smooth surface will require less binder than will a rough or porous surface. Table 7-5 details the correction factors associated with various existing pavement conditions

Table 7-5 Correction Factors Associated with Existing Road Conditions

(Jannisch, 1998)

EXISTING PAVEMENT	CORRECTION (G/YD2)
Black, flushed asphalt	-0.01 to -0.06 (Depending on severity)
Smooth, non-porous or smooth	0.00
Slightly porous and oxidized or matte	+0.03
Slightly pocked, porous, and oxidized	+0.06
Badly pocked, porous, and oxidized	+0.09

- **Embedment:** Aggregates may be punched or embedded into soft pavement surfaces by roller compaction and traffic. Table 7-6 provides corrections based on surface hardness and related traffic volume using a Ball Penetrometer test (Austroads, 1990)

Table 7-6 Binder Content Correction Based on Surface Hardness and Related Traffic Volume (Austroads, 1990)

SURFACE HARDNESS	TRAFFIC VOLUME (AADT PER LANE)				
	150 -300	300 -625	625 -1250	1250 -2500	>2500
Hard (Ball Value 1 – 2)	Nil	Nil	Nil	-0.1 l/m^2	-0.2 l/m^2
Medium (Ball Value 3 – 4)	Nil	Nil	-0.1 l/m^2	-0.2 l/m^2	-0.3 l/m^2*
Soft (Ball Value 5 – 8)	-0.1 l/m^2	-0.1 l/m^2	-0.2 l/m^2	-0.3 l/m^2	-0.4 l/m^2*

**Where embedment allowances of 0.3 l/m^2 or more are indicated, consideration should be given to alternative treatments such as multiple chip seal (armor-coating) with higher quality materials rolled into the surface, or the use of a primer seal/ prime and seal with a small aggregate in order to provide a platform on which a larger aggregate seal may be placed.*

Aggregate Application

Calculation of the design aggregate application rate is based on determining the amount of aggregate needed to create an even, single coat of chips on the pavement surface. Though not used by Caltrans, the amount of cover aggregate required can be determined using the following equation (Jannisch, 1998):

$$C = 46.8\,(1 - 0.4V) \times H \times G \times E \qquad (7.4)$$

where:

C = Cover Aggregate (lbs/yd2)
V = Voids in Loose Aggregate (%)
H = ALD (mm) – (See Figure 7-3)
G = Bulk Specific Gravity – (See CT 206 & CT 208)
E = Wastage Factor (%)

Equation 7.1 is used to calculate H (average least dimension) and Equation 7.2 is used to calculate V (voids in loose aggregate). The bulk specific gravity of coarse and fine aggregates, G, can be determined using CT 206 and CT 208, respectively. The wastage factor (E) is to account for whip-off and handling and is normally estimated by the designer based on experience with local conditions. While other design methods are available, Equation 7.4 provides a good starting point and covers most situations. It requires that the user consider the attributes of the surface being sealed and the conditions to which it will be subjected, which are both very important.

The design of multiple coat seals is based on the same concepts as the single chip seal. First, a design is performed for each layer as if it were the only layer in the system. Next, the following three additional rules are applied as follows: 1) the maximum nominal top size of each succeeding layer of cover aggregate should be no more than half the size of the previous layer's aggregate; 2) no allowance is made for wastage; and 3) except for the first application, no correction is made for the underlying surface texture. The amounts of binder determined for each layer of aggregate are added together to calculate the total binder requirement. For two-layer chip seals, 40% of the total binder requirement is applied for the first layer of aggregate and the remaining 60% is applied for the second layer.

Application Rates

Typical application rates for PME chip seal vary from 0.25 to 0.40 gal/yd^2 and for polymer modified asphalts they should not exceed 0.50 gal/yd^2. For asphalt rubber (e.g., SAMI's), typical binder application rates of 0.55 to 0.65 gal/yd^2 are used. For asphalt rubber seals, the binder application rate is significantly higher compared with the base application level calculated for unmodified binder. The higher binder rates are possible due to the higher viscosity of these binders. Application of cover aggregate should be the same in a SAM or SAMI to avoid damage to the membrane due to pick-up by the construction equipment or when the membrane is opened to traffic. Caltrans practices for Chip seals (or Seal coats) are summarized in their standard specifications, Section 37-1.05.

7.4 CONSTRUCTION

7.4.1 Construction Process

The sequence of construction events for chip seals is as follows:

1. Project Preparation
2. Surface Preparation
3. Binder Application
4. Aggregate Spreading
5. Rolling
6. Sweeping (Brooming)

Figure 7-7 illustrates the construction process from binder application through final sweeping. Details of the construction process are provided in the following sections.

7.4.2 Preparation

Preparation of the surface is critical to the performance of the chip seal. Areas of the pavement exhibiting structural failures (such as potholes and deteriorated patches) should be addressed by the removal or patching and sealing of the failed area. Avoid the use of cold mix for patching prior to applying the chip seal. Finally, the prepared surface must be clean, dry and free of any loose material before applying the binder. Preparation for a chip seal project typically includes:

- Milling of the Surface (if there is extensive loose material or areas of bleeding that must be removed)
- Crack Sealing or Filling of Cracks (that are likely to reflect through the chip seal- see Chapter 4)
- Patching any Deteriorated Areas or Dig Outs Where Required (see Chapter 5)
- Cleaning or Brooming any Loose Material from the Pavement Surface (such as areas of raveling)
- Removing Pavement Markers and Delineators

If the patched areas or newly placed patches are generally more porous than the rest of the pavement, a fog seal or tack coat prior to chip sealing may be required. Known shaded areas that seldom get sunlight (i.e. under bridge decks) may need a tack coat as well to prevent rock loss.

a) Binder Application

b) Spreading of Aggregate

c) Rolling

d) Sweeping

Figure 7-7 Construction Process for Chip Seals

Materials

A work site needs to contain a facility for storing aggregate and binder. Generally, binders are trucked directly from the manufacturer and off loaded for use. However, situations arise when distance and weather create the need for off site storage. The site should be chosen well in advance of project start-up. The aggregate stockpile should ideally be placed on a sloped and paved surface, but at least on a sloped surfaced to promote drainage of the stockpile. It should also ideally be protected from contamination with foreign material. Once stockpiled, the aggregate should not be moved until it is to be transported to the road being chip sealed. Following project completion, any remaining aggregate must be removed from the stockpile site and the site restored to its original condition before being used as a stockpile site. The methods for storing and handling binders and aggregates, for chip seals, is the same as those for terminal storage as outlined in Chapter 2 of this guide.

Weather Conditions

On the actual day when chip seals are constructed the weather should be clear and warm. In general, pavement surface temperatures should be 80°F and above, and the humidity should be 50% or lower. Wind may cause the emulsion spray to be diverted and compromise uniformity of application rate. A gentle breeze will assist in accelerating cure times. Any rainfall immediately before, during or after the construction of the PME chip seal will contribute to failure of the treatment. Thus, placement of chip seals should be avoided during such conditions. The actual requirements vary for different binder types and are included in the Caltrans specifications.

Traffic Control

The Resident Engineer (RE) examines and approves the contractor's traffic control plan prepared in accordance with the Caltrans Safety Manual (Caltrans, 1998) and the Caltrans Code of Safe Operating Practices (Caltrans, 1999c). The signs and devices used must match the traffic control plan. The work zone must conform to Caltrans practice and requirements set forth in the Caltrans Safety Manual and the Caltrans Code of Safe Operating Practices. All workers must have all required safety equipment and clothing.

After chipping, pilot cars should be used for between 2 and 24 hours to ensure that traffic speed is limited to approximately 20 mph (30 kph).

7.4.3 Joints

To ensure that the transverse joints are clean and sharp, chip seal passes should begin and end on felt paper or equal or follow the specification requirements. Longitudinal joints may be made with an overlap. In this process a wet edge (i.e., one without an application of aggregate) of 3 to 4 in (75 to 100 mm) is left (not in a wheel path) and the next run overlaps this wet edge. The chip distributor then covers the whole run to the pavement's edge. Figure 7-8 illustrates the layout of felt paper at the end of a project lane.

7.4.4 Spraying Equipment

The spray distributor is the most important piece of equipment in the chip seal process. Its function is to uniformly apply the binder over the surface at the designed rate. Typically, spray distributors (boot trucks) are truck mounted as shown in Figure 7-9, but trailer units have also been used. A distributor should have a heating, circulation, and pumping system, along with a spray bar, and all necessary controls to guarantee proper application.

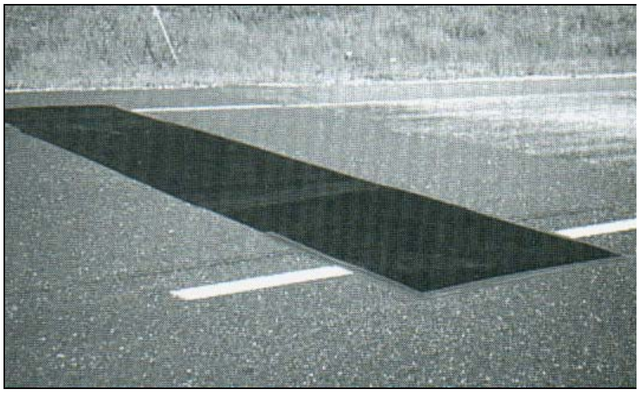


Figure 7-8 Start and Stop Passes on Roofing Felt (Transverse Joints)

Figure 7-9 Spray Distributor

Distributor Preparation

The steps associated with preparing the distributor include:

a) Calibrate the distributor by spraying a pre-weighed area of carpet (backed with a waterproof layer) and subtracting the initial weight from that of the sprayed carpet, then dividing the difference by the area of the carpet. Although this is the responsibility of the contractor, the inspector should verify that the distributor is spraying the binder at the correct application rate. See CT 339 for calibration procedures.
b) Blow the spray nozzles to ensure there are no blockages and checking the nozzle angles (see Figure 7-10) to ensure they spray at an angle 15 to 30 degrees from the spray bar axis. Often, the outer-most nozzles will be turned in to give a sharp edge with no over spray.
c) Check the distributor bar's height. The height is usually set so that a double or triple overlap is obtained as illustrated in Figure 7-11.
d) Check the distributor bar's transverse alignment to ensure it is closely perpendicular to the centerline of the pavement
e) Check the binder temperature to ensure it is in the appropriate range for proper application. Chip seal emulsion should be between 104 and 185°F (40 and 85 °C) (McLeod, 1969).
f) Ensure an adequate supply of binder is available.

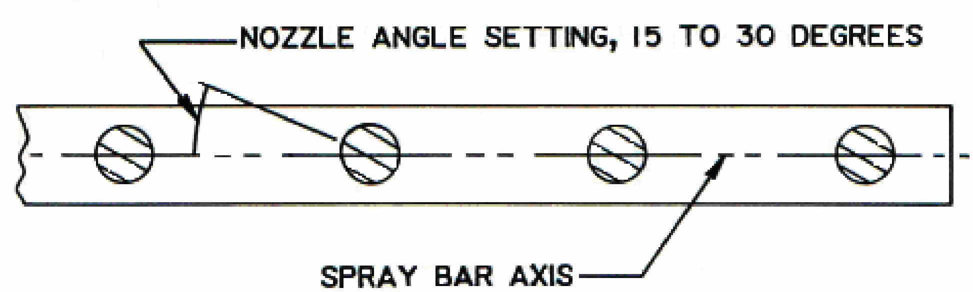


Figure 7-10 Spray Bar with Nozzle Arrangement (McLeod, 1969)

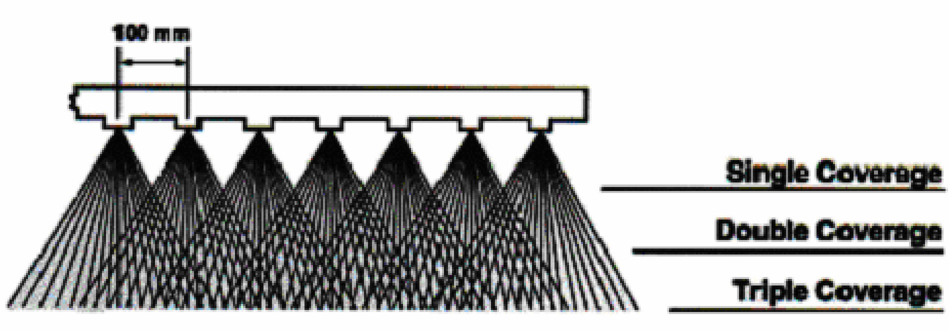


Figure 7-11 Spray Bar Height Arrangements (McLeod, 1969)

Visual checks should be made throughout the spraying process to ensure that the spray bars are clean and are spraying even fans. There should be no streaking of binder visible on the surface. If streaking occurs, the operation should be stopped to recheck proper functioning of the spray bar as well as proper binder temperature. The inspector should check application rates frequently. The application rate can be checked using the calibration method mentioned above or using the alternative method outlined in Section 7.6.2 Field Considerations of this chapter. The method above is recommended for equipment calibration while the alternative method is appropriate for quick spot-checking during construction.

For scrub seals the process is identical to that of a standard chip seal with the exception of the scrub broom which is used to force the emulsion into the crack. The wave of emulsion carried by the scrub broom is a function of the amount of cracking in the roadway. In addition, a PMRE can be applied at a rate of 10-15 % less than required by the standard PME. Unlike PME chip seals, cracks do not need to be sealed prior to applying the surface treatment. Figure 7-12 shows the scrub broom in action.

Figure 7-12 Scrub Seal Application

Chip Spreader

Chip spreaders must be able to spread an even coating of aggregate one layer thick over the entire sprayed surface. Figure 7-13 shows a typical chip spreader.

Figure 7-13 Chip Spreader

Prior to applying aggregate on a project, the following steps should be taken:

a) Calibrate the spreader by spreading chips over a pre-weighed area of carpet and subtracting the initial weight from that of the carpet with chips spread onto it, then dividing the difference by the area of the carpet. Although this is the responsibility of the contractor, the inspector should verify that the spreader is applying the aggregate at the correct application rate.
b) Ensure all gates in the spreader open correctly.
c) Ensure the spreader applies the aggregate is an even, single-layer thickness.
d) Ensure that the spreader is not leaving piles of aggregate and is not spreading too thick a layer. Too thick a layer of aggregate can result in the aggregate being crushed under rollers or by traffic, compromising the seal. Too thick a layer of aggregate can also result in the lever and wedge effect illustrated in Figure 7-14, which also compromises the seal.
e) Ensure an adequate supply of aggregate is available prior to applying the binder.
f) Ensure proper moisture content of aggregate for PME chip seals.

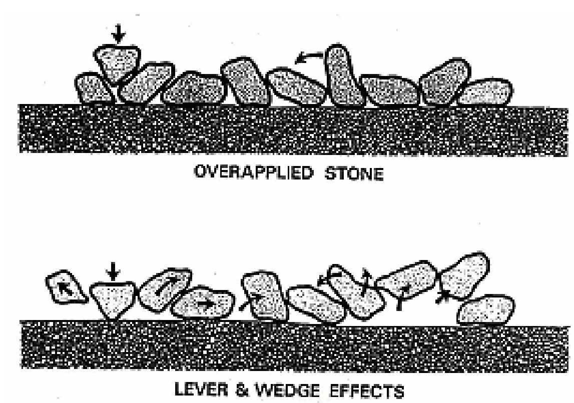


Figure 7-14 Lever and Wedge Effect (South Australian DOT, 1995)

Chip Spreading Process

The application of aggregate should follow the binder application by no more than 90 seconds in order to obtain the best possible aggregate retention. A good visual check is that the spreader should be no more than 100 ft (30 m) behind the distributor truck. The first chip spreading pass is usually done against traffic to allow good centerline match up. The direction for spreading is chosen mostly to minimize truck movements on the fresh oil.

Visual checks of the spreading include checking that the aggregate does not roll or bounce when applied. The flow of aggregate should also be checked. If a wave of binder forms in front of the blanket of aggregate, the binder application may be too heavy. The scalping screen should also be checked for build up of clay or other contaminants. If such contamination is heavy, it may be necessary to re-screen the stockpile. The spread pattern should be even without ripples or streaks. If ripples or streams occur, the spreading gates may need to be lowered and the machine slowed down.

7.4.5 Haul Trucks

Haul trucks are responsible for providing a continuous supply of binder to the site and aggregate to the spreader. Haul trucks should be in good mechanical condition. Leaking haul trucks can compromise the seal binder. Single axle trucks carry between 5 and 7 tons (4,500 and 6,350 kg) and trucks with tandem axles between 11 and 14 tons (9,000 and 12,700 kg). For this reason, trucks with tandem axles are the preferred. The increased capacity requires fewer hook ups resulting in less chance for spillage and a more efficient operation.

Tires on the trucks should be examined for binder pick up. If pick up occurs, it may severely damage the mat. Tires should be cleaned and sanded. Trucks should not drive on the new surface unnecessarily and should never brake sharply. When driving on the fresh mat, wheel paths should be staggered to assist in embedding the aggregate uniformly. When pulling away from the spreader, trucks should move smoothly and slowly to prevent wheel spin and mat damage. Trucks shall not be allowed to lose or dump chips when pulling away from the chip spreader. No sharp turning movements or high speeds should be allowed on a newly constructed chip seal.

7.4.6 Rolling

The function of the roller is to embed the aggregate into the binder and orient it into an interlocking mosaic. This is initially accomplished with pneumatic rollers as shown in Figure 7-15; compaction applied by traffic finish the process. Rolling should be expedited in hotter weather to ensure proper embedment of the aggregate. Steel rollers are not normally recommended for chip seals because they can crush the aggregate.

The important variables when rolling chip seals are:

- Contact Pressure
- Number of Passes and Pattern
- Speed
- Smoothness of Tires
- Adequate Number of Rollers

Figure 7-15 Pneumatic (Rubber Tired) Roller

Rollers shall be pneumatic-tired type. A minimum of 2 pneumatic-tired rollers conforming to the provisions in Section 39-5.02, "Compacting Equipment," shall be furnished (Caltrans, 2006). Initial rolling shall consist of one complete coverage and shall begin immediately behind the spreader. Asphaltic emulsion and screenings shall not be spread more than 2,500 feet ahead of completion of initial rolling operations. Secondary rolling shall begin immediately after completion of the initial rolling. The amount of secondary rolling shall be sufficient to adequately seat the screenings and in no case shall be less than 2 complete coverages (Caltrans, 2006). When two rollers are used, three passes are sufficient; one forward, one in reverse, and the final pass extending into the next section.

7.4.7 Brooming

Brooming is required before, after, and sometimes during the chip seal operation. Before applying the chip seal the pavement must be swept clean of dust and debris. During a multi-coat sealing operation excess aggregate shall need to be broomed off between coats. After the chip seal has been constructed, excess aggregate must be broomed off to minimize whip-off by traffic.

Brooming is done using rotary brooms with nylon or steel bristles or with vacuum mobile pickup brooms. The broom should not be worn, and should not be operated in such a manner that removes embedded aggregate. Figure 7-16 illustrates a typical brooming operation.

Mobile pickup brooms are usually capable of picking up aggregate and storing it. Sometimes so-called “kick brooms” are used. These brooms move the aggregate into a windrow so that it can be collected, but they often generate dust and may sweep aggregate into watercourses or gutters. Figure 7-17 illustrates a typical kick broom.

Brooming can generally be done within 2 to 4 hours after sealing. Hot applied chip seals can be swept within 30 minutes while conventional chip seals can be swept in 2 to 4 hours. A flush coat shall be applied after brooming to eliminate further rock loss and improve durability prior to opening the pavement to uncontrolled traffic.

Figure 7-16 Brooming Process, Shown on a Shoulder Seal

Figure 7-17 Kick Broom

7.5 FIELD TESTING

Most tests of constructed chip seals are empirical and provide the user an indication of what extra adjustments must be made on the job site. Though not used by Caltrans, the Ball Penetrometer Test (Austroads, 1990) and the Sand Patch Test (ASTM E965) are useful methods for checking the condition of the original pavement and the final seal. In the Ball Penetrometer Test, a ball is hammered on the pavement surface using a Marshall hammer a predetermined number of times. The amount of ball penetration into the existing surface is an indicator of the pavement's hardness with typical values ranging from 0 to 0.02 in (0 to 0.5 mm). The Sand Patch Test provides surface texture information for classifying surface type or examining seals with typical texture depths ranging from 0.04 to 0.1 in (1 mm to 2.5 mm) depending on the aggregate size. Figure 7-18 illustrates a technician performing the Ball Penetrometer Test and the Sand Patch Test.

a) Ball Penetrometer Test

b) Sand Patch Test

Figure 7-18 Field Test Methods

7.6 TROUBLESHOOTING AND FIELD CONSIDERATIONS

7.6.1 Troubleshooting Guide

This section provides information to assist maintenance personnel in troubleshooting problems with chip seals. The guide, along with a related table on problems and solutions, address common problems encountered during the course of chip seal projects.

The troubleshooting guide presented in Table 7-7 associates common problems to their potential causes. In California, the most common problem is flushing. In addition to the troubleshooting guide, Table 7-8 lists some commonly encountered problems and some recommended solutions.

Table 7-7 Troubleshooting Chip Seal Problems (Hot/Emulsion/Asphalt Rubber)

CAUSE	PROBLEM										
	Excessive Loss of Aggregate	Crushing of Aggregates	Pickup of Binder	Adhesion Problems	Raveling of Aggregates	Streaking of Binder	Transverse Patches	Flushing	Failure in Shade	Polishing of Aggregate	Poor Mosaic of Finished Mat
Poor Traffic Control	●		●		●				●		●
Poor Equipment	●		●		●		●	●	●		●
Spray Temperature	●		●		●	●	●		●		●
Vehicle Speeds	●				●	●	●	●	●		●
Distributor Nozzles	●				●	●		●	●		
CLIMATIC CONDITIONS											
Cold Surfaces	●			●	●				●		●
Wet	●			●	●				●		●
Windy	●			●	●				●		●
BINDER											
Wrong Binder	●		●	●	●	●		●	●		●
Too Little Binder	●			●	●				●		●
Too Much Binder	●		●					●			●
AGGREGATE											
Too Little	●		●					●			●
Too Much	●	●		●	●		●		●		●
Wet	●			●	●			●	●		●
Dirty	●			●	●				●		●
Quality	●	●		●	●				●	●	
Wrong Size	●				●			●	●	●	●
PRE-COAT											
Too Little	●			●	●				●		
Too Heavy	●				●						

Table 7-8 Common Problems and Related Solutions

PROBLEM	SOLUTION
Streaking or drill marks in the emulsion	• Ensure emulsion is at correct application temperature • Ensure the viscosity of the emulsion is not too high • Ensure all the nozzles are at the same angle • Ensure the spray bar is not too high or too low • Ensure the spray bar pressure is not too high or too low • Ensure nozzles are not plugged
Exposed emulsion after chip application	• Ensure the chip spreader gate is not clogged or malfunctioning • Ensure the chip spreader is covering all the binder
Excessive chips/Many chips with small amounts of emulsion	• Ensure the chip spreader gate is not malfunctioning or chipper head is not overloaded • Lower the chip application rate
Uneven chip application	• Re-calibrate the chip spreader; ensure all spreader gates are set the same
Emulsion on the top of chips	• Ensure the chip spreader is not operating too fast • Ensure trucks, rollers, and pilot cars are operating correctly at low speeds
Chips being dislodged	• Ensure the emulsion application is not too light • Ensure the chips are not dirty or dusty • Ensure the traffic or equipment speeds are not too high • Ensure brooming does not occur before the emulsion is properly set
Emulsion bleeding or flushing	• Ensure the emulsion application is not too high • Ensure the aggregate application is not too low
After brooming, loss of chip at centerlines	• Check centerline procedure • Check binder application rate
Excessive splattering of the emulsion	• Lower the spray pressure

7.6.2 Field Considerations

The following field considerations are a guide through the important aspects of performing a chip seal project. The various tables list items that should be considered in order to promote a successful job outcome. The answers to these questions should be carefully evaluated before, during and after construction. The appropriate staff to do this will vary by job type and size, and some topics may need attention from several staff. The field supervisor should be acquainted with its contents. Responses to the questions in these tables are not meant to form a report, but rather to call attention to important aspects and components of the chip seal project process. Some information is product-specific and contained in the relevant standard specifications, standard special provisions, or special provisions.

PRELIMINARY RESPONSIBILITIES	
PROJECT REVIEW	• Is the project a good candidate for a chip seal? • How much rutting is present? • How much and what type of cracking exists? • Is crack sealing needed? • How much bleeding or flushing exists? • Review project for bid/plan quantities.
DOCUMENT REVIEW	• Bid Specifications • Special Provisions • Construction Manual • Traffic Control Plan (TCP)
MATERIALS CHECKS	• The type of binder to be used is compatible with the chips? • The binder is from an approved source (if required)? • The binder and aggregate have been sampled and submitted for testing (if required)? • All chips are close to the same size? • The chips are clean and free of excess fines? • The chips used with emulsions are in a surface-damp condition? • Is the emulsion temperature within application temperature specification?
SURFACE PREPARATION	• Is the surface clean and dry? • Have all pavement distresses been repaired and sealed? • Has the existing surface been inspected for drainage problems? • Have pavement markers been removed and temporary markers placed?

EQUIPMENT INSPECTIONS	
BROOM	• The bristles are the proper length? • The broom can be adjusted vertically to avoid excess pressure? • Are water misters operable?
DISTRIBUTOR	• Is the spray bar at the proper height? • Are all nozzles are uniformly angled 15 to 30 degrees from the spray bar? • Are all nozzles free of clogs? • Is the spray pattern uniform and does it properly overlap (double or triple)? • Is the application pressure correct? • Is the distributor properly calibrated and correct size nozzle tips installed?
CHIP SPREADER	• Do the spreader gates function properly and are their settings correct? • Is the scalping screen in good condition? • Is the chip spreader's calibration uniform across the entire chipper head? • Are the truck hook-up hitches in good condition?
ROLLERS	• What type of roller will be used on the project (pneumatic-tired roller recommended)? Do rollers meet weight requirements? • Does the roller tire sizes, ratings, and pressures comply with the manufacturer's recommendations and specifications? • Are the tire pressures the same on all tires? • Do all tires have a smooth surface?
HAUL TRUCKS	• Is the truck box clean and free of debris and other materials? • Is the truck hook-up hitch in working order? • Is a truck box apron or extension required for loading the chip spreader?
WEATHER REQUIREMENTS	• Do the specifications describe a range of dates when chip sealing can be done? • Air and surface temperatures have been checked at the coolest location on the project? • Air and surface temperatures meet agency requirements? • Are high winds expected? High winds can create problems with the emulsion application. • Will the expected weather conditions delay the breaking of the emulsion? High temperatures, humidity, and wind will effect how long the emulsion takes to break. • The application of emulsion should not begin if rain is likely within 24 hours.

<table>
<tr><th colspan="2">EQUIPMENT INSPECTIONS</th></tr>
<tr><td>DETERMINING APPLICATION RATES</td><td>

Agency guidelines and requirements have been followed?
Has a chip seal design been done?
Is the surface oxidized or porous? More oil is applied to dried-out and porous surfaces.
Is the traffic volume on the road low? More oil is applied on roads with low traffic volumes.
Is the surface smooth, non-porous, or bleeding? Less oil is applied to smooth, non-porous, and asphalt-rich surfaces.
Is the traffic volume on the road high? Less oil is applied on roads with high traffic volumes.
Is there a salt and pepper appearance after the chips have been applied?

</td></tr>
<tr><th colspan="2">BINDER CALIBRATION CONSIDERATIONS</th></tr>
<tr><td>CHECKING APPLICATION RATES</td><td>
Binder – Method A (Recommended for Calibration)

The weight of a 1yd^2 (0.84 m^2) carpet, pan, or non-woven geotextile material is recorded.
The carpet, pan, or non-woven geotextile material is placed on the road surface.
The distributor applies oil over the carpet, pan, or geotextile material.
The weight of the carpet and oil, pan and oil, or geotextile material and oil is recorded.
The weight of the carpet, pan, or geotextile material without oil is subtracted from the weight of the carpet, pan, or geotextile material with emulsion.
The weights applied to the area of carpet (i.e., lb/yd^2 or kg/m^2) must be converted to the units of the control mechanism, which is gal/yd^2 or l/m^2, through knowledge of the specific gravity of the emulsion. If the distributor is not spraying the binder at the correct application rate, adjustments must be made to the controls and the process described above repeated until the correct application rate is achieved. Although this is the responsibility of the contractor, the inspector should verify that the distributor is spraying the binder at the correct application rate.

</td></tr>
</table>

BINDER CALIBRATION CONSIDERATIONS	
CHECKING APPLICATION RATES	**Binder – Method B (Recommended for Random Checks)** • Park the distributor on level ground and measure the number of liters or gallons of emulsion. Mark the locations of the front and back tires. • Measure off a known distance for a test section. • Have the distributor apply emulsion to the test section. • Return the distributor to the original level ground and re-measure the number of liters or gallons of emulsion. • Subtract the number liters or gallons after application from the original number of liters or gallons to obtain the number of liters or gallons applied. • Divide the number of liters or gallons applied by number of square meters or square yards covered by emulsion to give the application rate in gal/yd^2 or l/m^2. • If the distributor is not spraying the binder at the correct application rate, adjustments must be made to the controls and the process described above repeated until the correct application rate is achieved. Although this is the responsibility of the contractor, the inspector should verify that the distributor is spraying the binder at the correct application rate.
CHIP CALIBRATION CONSIDERATIONS	
CHECKING APPLICATION RATES	**Chips – Method A (Recommended for Calibration)** • Weigh a 1 yd^2 (0.84 m^2) tarp or geotextile material. • Place the tarp or geotextile material on the roadway. • Have the chip spreader apply the chips over the tarp or geotextile material. • Weigh the tarp or the geotextile material with the chips. • Subtract the original weight of the tarp or geotextile material from the weight of the tarp or geotextile with the chips. Divide the weight of the chips by the area of the tarp or geotextile to give the application rate in lb/yd^2 or kg/m^2.

CHIP CALIBRATION CONSIDERATIONS	
CHECKING APPLICATION RATES	**Chips – Method B (Recommended for Random Checks)** • Weigh a haul truck empty. • Load the haul truck with chips and reweigh the truck. • Subtract the weight of the empty truck from that of the loaded truck to obtain the weight of the chips. • Empty all the chips into the chip spreader. • Have the chip spreader apply all of the chips from the weighed truck. • Measure the length and width of the area over which the chips were spread. • Divide the weight of the chips by the area over which they were spread to determine actual rate in lb/yd^2 or kg/m^2.

PROJECT INSPECTION RESPONSIBILITIES	
BINDER APPLICATION	• Is roofing felt or building paper used to start and stop binder application? • Is the binder within the required application temperature range? • Does the application look uniform? • Are any nozzles plugged? • Is there streaking in the applied binder? • Are application rates randomly checked? • Is the speed of the distributor adjusted to match the chip spreader to prevent stop-and-start operations? • Is the distributor stopped if any problems are observed?
CHIP APPLICATION	• Are enough trucks on hand to maintain a steady supply of chips to the spreader? • The application starts and stops with neat, straight edges? • The binder application starts and stops on building paper or roofing felt? • The chip spreader follows closely (33 yds] or less) behind the distributor when an emulsion is used? • The chip spreader travels slowly enough to prevent chips from rolling when they hit the surface? • Are the chips in a surface damp condition? • No binder is on top of the chips? • The application is stopped as soon as any problems are detected? • Does the application appear uniform? • Do the chips have a salt and pepper appearance? • Check the percent chip embedment in the binder and adjust binder or chip application rate if required.

PROJECT INSPECTION RESPONSIBILITIES	
TRAFFIC CONTROL	• The signs and devices used match the traffic control plan? • The work zone complies with Caltrans methods? • Flaggers do not hold the traffic for extended periods of time? • The pilot car leads traffic slowly — 25 mph (40 kph) or less—over fresh chip seals? • Signs are removed when they no long apply? • Any unsafe conditions are immediately reported to a supervisor?
ROLLING	• The rollers follow closely behind the chip spreader? • The entire surface is rolled at least twice? • Roller speeds kept at 5 mph (8-9 kph) maximum? • The roller's first pass is on the meet line? • Rollers do not drive on exposed emulsion? • All stop, starts, and turns are made gradually?
TRUCK OPERATION	• Trucks travel slowly on the fresh seal? • Stops and turns are made gradually? • Truck operators avoid driving over exposed binder? • Trucks stagger their wheel paths when backing into the chip spreader? This helps to eliminate chip roll over and aids in rolling.
LONGITUDINAL JOINTS	• The meet line is only as wide as the spray from the end nozzle—about 8 in (20 cm)? • The distributor lines up so that the end nozzle sprays the meet line? • The meet lines are not made in the wheel paths? • The meet lines are made at the center of the road, center of a lane, or edge of a lane? • The meet lines are not left uncovered overnight?
TRANSVERSE JOINTS	• All binder and chip applications begin and end on building paper or roofing felt? • The building paper or roofing felt is disposed of properly?
BROOMING	• Brooming does not dislodge the aggregate? • Brooming begins as soon as possible, but not until sufficient bond has formed between the chip and the binder? Check with the binder manufacturer for their recommendation or refer to agency requirements. • Are misters on mobile pickup brooms operating?

PROJECT INSPECTION RESPONSIBILITIES	
OPENING THE CHIP SEAL TO TRAFFIC	• Traffic travels slowly–24 mph (40 kph) or less–over the fresh seal coat until the chip seal is broomed and opened for normal traffic? • Reduced speed limit signs are used when pilot cars are not used? • Are pavement markings placed before opening chip seal to normal traffic? • Are all construction-related signs removed when opening chip seal to traffic and traffic control is removed?
CLEAN UP	• Is all loose aggregate from brooming removed from the roadway? • Are binder spills cleaned up?

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CHAPTER 8 SLURRY SEALS

8.1 OVERVIEW

This chapter provides an overview of the types of slurry seals presently used in California, including materials and specifications, mix design, project selection, details regarding construction, a troubleshooting guide to assist the Engineer if problems arise during the placement of these mixtures, and a listing of suggested field considerations when placing a slurry surfacing.

8.1.1 General Description

Slurry seals are a mixture of asphalt emulsion, graded aggregates, mineral filler, water and other additives. The mixture is made and placed on a continuous basis using a travel paver (Slurry Surfacing Machine). The travel paver meters the mix components in a predetermined order into a pug mill. The typical mixing order is aggregate followed by cement, water, the additive and the emulsion. Figure 8-1 illustrates the process of slurry surfacing.

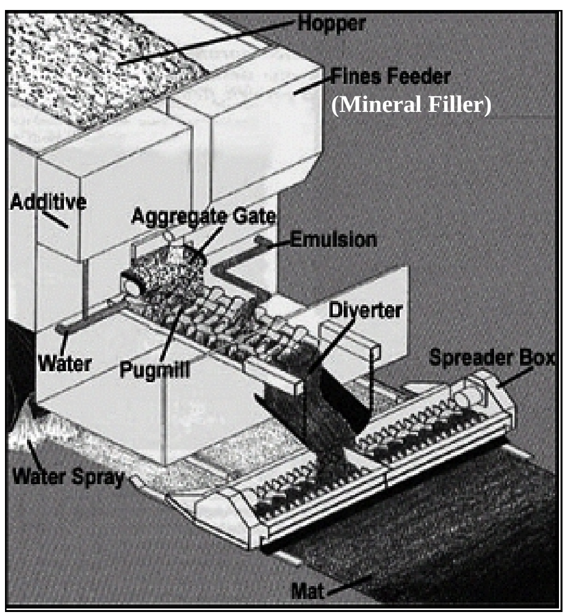


Figure 8-1 Schematic of a Slurry Surfacing Machine (Holleran, 2001)

The resulting slurry material is a free flowing composite material that is spread via a spreader box over the existing road surface. The consistency of the slurry material allows it to spread over the pavement, wetting it, and forming an adhesive bond to the pavement.

The slurry mixture contains asphalt emulsion that breaks onto the pavement surface through heterogeneous or homogenous flocculation. The asphalt particles coalesce into films, creating a cohesive mixture. The mixture then cures, by loss of water, into a hardwearing, dense-graded asphalt/aggregate mixture that is bonded to the existing pavement.

A slurry surfacing does not add any structural capacity to an existing pavement; they are applied as a maintenance treatment to improve the functional characteristics of the pavement surface. The types of slurry surfacing and the pavement characteristics they improve are discussed next.

8.1.2 Purpose of a Slurry Seal

A slurry seal is a thin surface treatment that is laid in a thickness equal to the largest stone in the grading of its component aggregate. It may include either a conventional or polymer modified emulsion, and the slurry seal may be slow or quick setting. The emulsion is usually cationic in nature, but may be anionic. Slow set systems break mostly by evaporation; quick set systems have emulsifiers that react chemically with the aggregate surfaces. These quick set emulsions maintain a degree of chemical break. For both systems, breaking and curing times are strongly influenced by the environmental conditions at the time of application; at high temperatures the emulsion in quick set systems breaks and cures very quickly such that the surface treatment can be opened to traffic within a few hours; slow set systems typically require a longer time to break and cure. In cooler conditions, the times before opening to traffic are longer for both systems. For this reason, slurry seals should not be applied at night.

A slurry seal is used to:

- Seal sound and oxidize pavements
- Restore surface texture by providing a skid-resistant wearing surface
- Improve waterproofing characteristics
- Correct raveling
- Provide a new surface where weight restrictions preclude the use of heavier overlays (e.g., bridge decks), and
- Provide a new surface where height restrictions are a problem (e.g., overcrossings).

A slurry seal should not be used to:

- Correct surface profile
- Fill potholes, and
- Alleviate cracking (with or without polymer modification)

8.2 MATERIALS

The main materials used in slurry surfacing are:

- Asphalt Emulsion

- Water
- Aggregate
- Mineral Filler
- Additives

8.2.1 Asphalt Emulsion

Asphalt emulsions are defined in Chapter 2 of this advisory guide as dispersions of asphalt in water stabilized by a chemical system. In the case of slurry surfacing, the emulsion may be cationic or anionic; however, cationic emulsions are the most common. Caltrans Standard Specifications Section 94 (Caltrans, 2006) provides specifications for the main emulsion types. Emulsions used in slurry seals are either slow setting (SS) or quick setting (QS). Common slow and quick setting emulsions include:

- CSS1h (Cationic Slow Set)
- CQS1h (Cationic Quick Set)
- SS1h (Anionic Slow Set)
- QS1h (Anionic Quick Set)

These emulsions are specially formulated for compatibility with the aggregate and to meet the appropriate mix design parameters. These emulsions are defined in Chapter 2 of this guide, Section 94 of the Standard Specifications (Caltrans, 2006), and in the ISSA Slurry Surfacing Workshop (Holleran, 2002) identified at the end of this chapter.

Emulsion specifications are based on standard emulsion characteristics, such as stability, binder content, and viscosity. In some quick set slurry systems polymer is added to the emulsion. The polymer enhances stone retention, especially in the early life of the treatment. The added polymer also reduces thermal susceptibility. Polymers also improve softening point and flexibility, which enhance the treatment's crack resistance.

Emulsions are usually modified with latex, which is an emulsion of rubber particles. The latex does not mix with the asphalt; rather, the latex and the asphalt particles intermingle to form a sort of 3-D structure, as illustrated in Figure 8-2. The latex used is either neoprene or styrene butadiene styrene (SBR) for slurry seal. When modified with latex, slurry seal emulsions are referred to PMCQS1h (Polymer Modified Cationic Quick Set) or, more commonly, LMCQS-1h (Latex Modified Cationic Quick Set, Holleran, 2001).

Latex may separate from the emulsion due to the differences in density. If separation occurs, the latex must be remixed into the emulsion by circulation in the tanker before the modified emulsion is transferred to the slurry machine for application (Holleran, 2002).

Basic emulsion requirements are shown in Table 8-1. Key requirements include the binder content and residual properties. The viscosity is of importance as is the storage stability to ensure that the emulsion can be used effectively in the field.

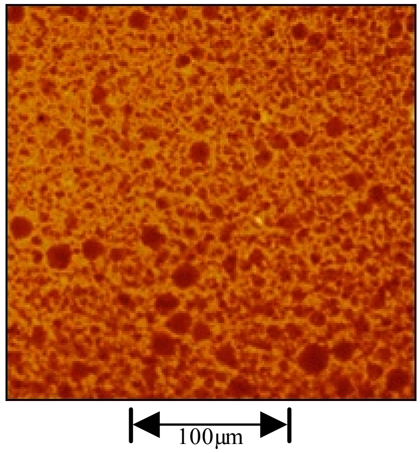


Figure 8-2 Micrograph of a Latex/Asphalt Cured Film (Holleran, 2002)

Table 8-1 Typical Emulsion Properties for Quick Setting Asphalt Emulsions (Caltrans, 2006)

Tests on Emulsion	**Typical Specification**	**Method**
Viscosity, SSF @ 50°C, sec	15 – 90	AASHTO T 59
Settlement, 5 days, %	< 5	ASTM D 244
Storage Stability, 1 day, %	< 1	AASHTO T 59
Sieve Test, %	< 0.30	AASHTO T 59
Demulsibility, %	> 40	
Particle Charge	Positive	
Ash Content, %	< 0.2	ASTM D 3723
Residue by Evaporation, %	> 65	California Test 331
Tests on Residue from Evaporation Test	**Typical Specification**	**Method**
Penetration, 25°C	< 90	AASHTO T 49
Ductility, 25°C, mm	> 400	AASHTO T 51
Torsional Recovery, %	> 18 (LMCQS-1h)	California Test 332
Polymer Content, % (by weight)	> 2.5 (LMCQS-1h)	California Test 401

8.2.2 Aggregates

The aggregate's key physical characteristics for suitable incorporation into a slurry surfacing mix are defined by:

- **Geology:** This determines the aggregate's compatibility with the emulsion along with its adhesive and cohesive properties.

- **Shape:** The aggregates must have fractured faces in order to form the required interlocking matrix (Holleran, 2001). Rounded aggregates result in poor mix strength.
- **Texture:** Rough surfaces form bonds more easily with emulsions.
- **Age and Reactivity:** Freshly crushed aggregates have a higher surface charge than aged (weathered) aggregates. Surface charge plays a primary role in reaction rates.
- **Cleanliness:** Deleterious materials such as clay, dust, or silt can cause poor cohesion and adversely affect reaction rates.
- **Soundness and Abrasion Resistance:** These features play a particularly important role in areas that experience freeze-thaw cycles or are very wet.

Caltrans Standard Specifications, Section 37-2, specifies three aggregate grading sizes for slurry seals: Type I, II and III (Caltrans, 2006). The gradation for each type is listed in Table 8-2.

Table 8-2 Caltrans Slurry Surfacing Aggregate Gradings (Caltrans, 2006)

SIEVE SIZE	PERCENTAGE PASSING		
	TYPE I	TYPE II	TYPE III
3/8 in (9.5mm)	-	100	100
No. 4 (4.75 mm)	100	94-100	70-90
No. 8 (2.36 mm)	90-100	65-90	45-70
No. 16 (1.18 mm)	60-90	40-70	28-50
No. 30 (600-µm)	40-65	25-50	19-34
No. 200 (75-µm)	10-20	5-15	5-15

The primary difference among these gradations is the aggregate top size. This indicates the amount of residual asphalt required by the mixture and the purpose to which the slurry is most suited. The Type I slurries are the finest and are used for lightly trafficked roads or parking lots. Type II slurries are coarser and are suggested for raveling and oxidation on roadways with moderate to heavy traffic volumes. Type III slurries have the coarsest grading and are appropriate for filling minor surface irregularities, correcting raveling and oxidation, and restoring surface friction. Type III slurries are typically used on arterial streets and highways.

The role of fines (i.e., aggregate particles No. 200 [75 µm] and finer) in a slurry surfacing mix is to form a mortar with the residual asphalt to cement the larger stones in place. The fines content is essential for creating a cohesive hardwearing mix. Generally, the fines content should be at the mid-point of the grading envelope. The general aggregate quality requirements are listed in Table 8-3.

Table 8-3 General Aggregate Properties (Caltrans, 2006) and Aggregate Requirements (Schilling, 2002)

TEST	SLURRY SEAL TYPE			TEST # AND PURPOSE
	I	II	III	
Sand Equivalent (min)	45	55	60	CT 217 Clay Content
Durability Index (min)	55	55	55	CT 229 Resistance to wet/dry exposure

8.2.3 Mineral Filler and Additives

According to ISSA, the mineral filler can be Portland cement, hydrated lime, limestone dust, fly ash or other approved filler meeting the requirements of ASTM D242, and is considered part of the dry aggregate. The Caltrans specification does not provide any details on the mineral filler.

In most slurry surfacing, cement is used as a mixing aid allowing the mixing time to be extended and creating a creamy consistency that is easy to spread. Additionally, hydroxyl ions counteract the emulsifier ions, resulting in a mix that breaks faster with a shorter curing time. Cement is also a fine material and, as such, absorbs water from the emulsion, causing it to break faster after placement. Fine materials, as previously discussed, also promote cohesion of the mixture by forming a mortar with the residual asphalt.

Additives other than cement vary and are features of particular systems. They act as retardants to the reaction with emulsions, either as a prophylactic, slowing the emulsifier's access to the aggregate surface, or by preferentially reacting with the emulsifier in the system. Additives include emulsifier solutions, aluminum sulfate, aluminum chloride, and borax. Generally, increasing the concentration of an additive slows the breaking and curing times. This is useful when temperatures increase during the day.

8.3 MIX DESIGN

The performance of a slurry surfacing depends on the quality of the materials and how they interact during cure and after cure. The mix design procedure looks at the various phases of this process, which include:

- **Mixing:** Will the components mix together and form slurry with desired consistency?
- **Breaking and Curing:** Will the emulsion break in a controlled way on the aggregate, coat the aggregate, and form good films on the aggregate? Will the emulsion build up cohesion to a level that will resist abrasion due to traffic?
- **Performance:** Will the slurry surfacing resist traffic-induced stresses?

The steps in slurry design include:

- Prescreening of Materials

- Job Mix Design
- Final Testing

At each stage, mixing, breaking, curing, and performance issues are addressed.

8.3.1 Prescreening

Prescreening involves testing the physical properties of the raw materials. The emulsion type is selected based on job requirements and is checked against the requirements laid out in the specifications (Standard Specifications, Section 94). The aggregate is checked against specifications (Tables 8-2 and 8-3) and a simple mixing test is performed to assess compatibility with the emulsion. When both of these steps are satisfied, the job mix formula can be developed. During the overall process the materials may be changed at any time until satisfactory results are obtained.

8.3.2 Job Mix Design

Mix designs for slurry seals are generally done by private laboratories and follow the ISSA mix design procedure. The following sections discuss some of the design considerations for slurry seals

Mixing Proportions

The International Slurry Surfacing Association (ISSA) test method TB 102 (detailed in Technical Bulletin 102) is used to determine the approximate proportions of the slurry mix components (ISSA, 1991). In this test, a matrix of mix recipes are made up and the manual mixing time is recorded for each mixture. A minimum time is required to ensure that the mixture will be able to mix without breaking in the slurry machine. At this stage, phenomena such as foaming and coating are visually assessed. Also at this stage, the water content and additive content can be determined to produce a quality mixture. Figure 8-3 illustrates a good slurry mixture consistency.

Figure 8-3 Good Mixture Consistency

The mixing time must be at least 180 seconds for a slurry seal at 77°F (25°C). The process may be repeated at elevated or reduced temperatures to simulate expected field conditions at the time of application. The best mix is chosen, based on good coating of mixing times in excess of the minimum required through the entire range of expected application temperatures. This is a subjective test; the result is highly dependent on the operator

Cohesion Build-up

Once the emulsion content is determined, three mixes are then made, one at the selected emulsion percentage from above, one at -2% of the selected emulsion content and one at +2% of the selected emulsion content. This allows a bracketing of the desired mix proportions. The ISSA test method detailed in TB 139 (ISSA, 1991) is used to determine the cohesion build-up in a slurry mixture. This test may be performed at the expected field temperatures to provide the most accurate estimate of the treatment's characteristics. Table 8-4 lists mix requirements for slurry surfacing.

Abrasion Resistance (Wet Track Abrasion Test – WTAT)

Mixes are made at three emulsion contents, optimum, optimum +2%, and -2% of optimum. These mixes are then cured in circular molds for 16 hours at 140°F (60°C). The samples are then soaked for either 1 hour or 6 days, depending on the abrasion test (TB 100) (ISSA, 1991) and the material. Slurry design requires a 1-hour soaking. After soaking, a standard rubber hose is orbitally ground over the surface of the sample (while still submerged) for a set period of time. The wear loss is then calculated. The test equipment is shown in Figure 8-4, while the abrasion resistance requirements are listed in Table 8-4.

a) Mixer Equipped with sample Mold and Rubber Hose Attachment

b) Orbital Grinding of Sample Using Rubber Hose Attachment

Figure 8-4 Wet Track Abrasion Test Apparatus and Test in Progress

Table 8-4 Typical Mix Requirements (Caltrans, 2006)

PROPERTY	TEST	SLURRY SEAL REQUIREMENTS
Slurry Seal Consistency, in (mm)	TB 106	1.2 (30) max
Wet Stripping	TB 114	Pass
Compatibility	TB 115	Pass[a]
Cohesion Test [b], kg-mm within 1hour	TB 139	200 min.
Wet Track Abrasion, g/m^2	TB 100	800 max.

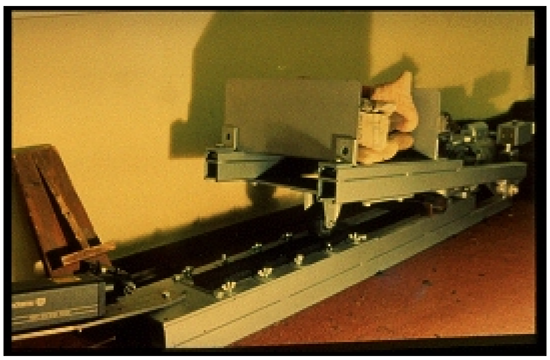
[a] Mixing test must pass at the maximum expected air temperature at the project site during application

[b] Using project source aggregate and asphalt emulsion and set-control agents if used

The results of the abrasion test are plotted along with the specification requirements. This allows selection of the minimum binder content of the mixture.

Upper Binder Limit

The upper binder limit is determined using the Loaded Wheel Test, as described in TB 109 (ISSA, 1991). In this test, the slurry seal specimen is compacted by means of a loaded rubber tired reciprocating wheel as illustrated in Figure 8-5. After 1000 loading cycles, the specimen is removed from the machine, washed and dried to constant weight. Then, the specimen is mounted again on the machine and hot sand is added on the surface. After another 100 cycles of compaction, the increase in weight of the specimen due to sand adhesion is noted. This provides a measure of the free asphalt on the surface of the sample. The more prone the mix is to flushing or bleeding under traffic loading the larger the amount of sand retained on the specimen. Figure 8-5 illustrates the test apparatus along with a series of tested samples.



a) Testing Apparatus

b) Tested Samples Showing Retained Sand

Figure 8-5 Loaded Wheel Test and Excess Asphalt Test Apparatus and Test Samples

Optimum Binder

The optimum percentage emulsion or binder content is found by plotting the results obtained from the Wet Track Test (TB 100) and the Loaded Wheel Test (TB 109) (ISSA, 1991). Figure 8-6 illustrates a typical plot of test results. The optimum binder content is chosen close to the intersection of the two plotted lines. The optimum binder content should be selected by an experienced designer based on field knowledge and experience. This is a weakness in the current design process.

8.3.3 Final Testing

Once the job mix components have been selected, the mix is tested to determine its properties and ensure compliance with the specifications listed in Table 8-4. If the mix conforms to the specifications, the emulsion content and aggregate grading is reported as the job mix formula.

Field adjustments may be made to the job mix formula to accommodate climatic variables during application. As a result of the mix design process, adjustments are limited to the amount of additives (cement and retardant) and water content required to ensure a good homogeneous mix at the time of application.

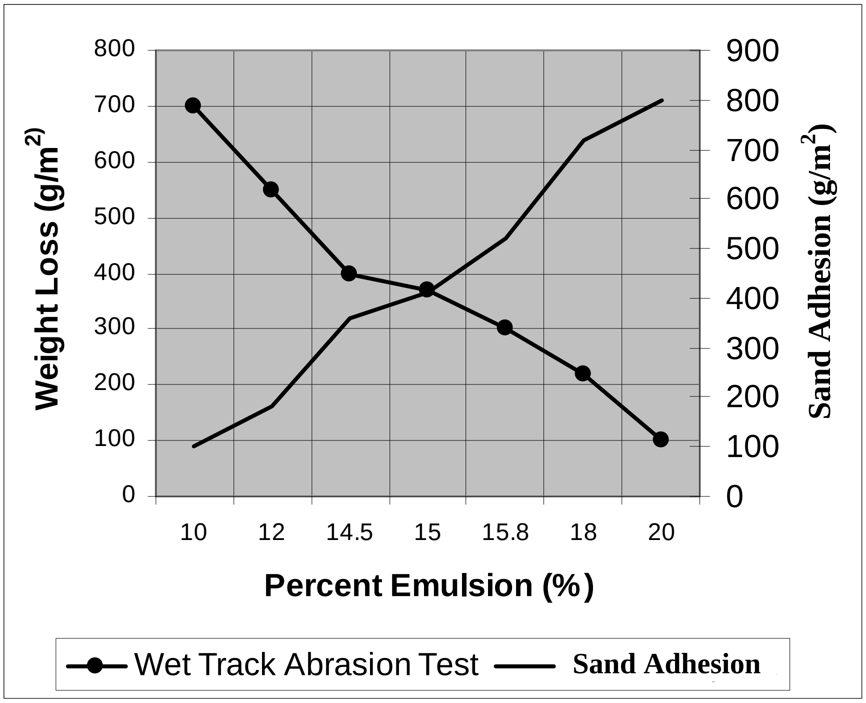


Figure 8-6 Determining Optimum Binder Content

8.3.4 A Modern, Rational Mix Design for Slurry Surfacing Systems

Recognizing the need for more rational design methods for slurry seal and micro-surfacing, the Federal Highway Administration (FHWA) enlisted the California Department of Transportation (Caltrans) to form a pooled fund study with the overall objective of developing a rational mix design method for slurry seal and microsurfacing. The improved mix design procedures, guidelines, and specifications will address the performance needs of the owners and users, the design and application needs of the suppliers, and improve the reproducibility of the test methods used for the mix designs. The pooled fund study project involves 13 State Departments of Transportation, was started din 2003 and is expected to end in 2008.

8.4 PROJECT SELECTION

8.4.1 Distress and Application Considerations

Slurry surfacing may be used for a range of applications, but job selection is critical and often pretreatments such as pothole patching, crack sealing, and dig outs are required. Table 8-5 lists general job selection criteria for slurry surfacing treatments and typical application rates.

The main use of slurry surfacing materials is for pavement preservation as a part of a program of periodic surfacing before distresses appear. The main criteria for project selection are:

- Sound and well drained bases, surfaces, and shoulders
- Free of distresses, including potholes and cracking

Table 8-5 Job Selection Criteria

APPLICATIONS	AGGREGATE TYPE		
	I	II	III
Void Filling	●	●	
Wearing Course (AADT) < 100	●	●	
Wearing Course (AADT) 100 – 1,000		●	●
Wearing Course (AADT) 1,000 – 20,000			●
Minor Shape Correction (0.4-0.8 in [10-20mm])			●
Application Rates in pounds of dry aggregate per square yard	8 - 12	10 - 15	20 - 25

Distress modes that can be addressed using slurry surfacing include:

- Raveling: Loose surfaces or surfaces losing aggregate may be resurfaced using slurry seals
- Oxidized pavement with hairline cracks: These surfaces may be resurfaced using slurry seals
- Friction Loss: Skid resistance can be restored by application of slurry seals

Distress modes that cannot be addressed using slurry surfacing include:

- Rutting
- Cracking (including reflection cracking)
- Base Failures (of any kind)
- HMA Layers that exhibit plastic shear deformation

Slurry surfacing will not alleviate the cause of these distresses. As a result, the distresses will continue to form despite the application of a slurry surfacing.

8.4.2 Performance of Slurry Seals

According to a California study, slurry seals have been estimated to last around 3 to 5 years (Van Kirk, 2004). Longer service lives (up to 15 years) have been observed when the seals are placed as true preventive maintenance treatments on suitable roads.

Traffic is not a limiting factor. The main failure mechanism is wear. Over time, the slurry surfacing oxidizes and abrades under traffic. Premature failure occurs from placement on highly deflecting surfaces, cracked surfaces, pavements with base failures, and on dirty or poorly prepared surfaces (resulting in delamination).

8.5 CONSTRUCTION

The main components of the construction process include:

- Safety and Traffic Control
- Equipment Requirements
- Stockpile/Project Staging Area Requirements

- Surface Preparation
- Application Conditions
- Types of Applications
- Quality Issues
- Post Construction Conditions
- Post-Treatments

Section 8.6.2, "Suggested Field Considerations", at the end of this chapter, provides a series of tables to guide project personnel through the important aspects of applying a slurry surfacing.

8.5.1 Safety and Traffic Control

Traffic control is required both for the safety of the traveling public and the employees performing the work. Traffic control should be in place before work forces and equipment enter onto the roadway or into the work zone. Traffic control includes construction signs, construction cones and/or barricades, flag personnel, and pilot cars to direct traffic clear of the maintenance operation. For detailed Traffic Control requirements, please refer to the Caltrans project specifications and the Caltrans Code of Safe Operating Practice (Caltrans, 1999).

Traffic control is required to ensure that the slurry surfacing has had adequate time to cure prior to reopening to traffic. The curing time for the slurry surfacing material will vary depending on the pavement surface conditions and the weather conditions at the time of application. It is recommended that the public is informed of the pavement maintenance activities that will take place in their neighborhood and that it is very important not to drive on the new surface for as long as the traffic signs are present. Very often drivers assume that the slurry surfacing is drivable despite of the warning signs and cause damage to the fresh placed treatment. Door knob cards are recommended to notify the residents and provide information on how to accommodate the construction activities. Additional traffic control considerations are listed in the Field Considerations section (8.6.2) of this chapter.

8.5.2 Equipment Requirements

Equipment requirements for slurry machines are covered in Caltrans Standard Specifications Section 37 (Caltrans, 2006). Calibration requirements are discussed in California test method CT 109. Modern equipment, as shown in Figure 8-7, can be used to place slurry seal.

A slurry seal spreader box is a drag box, as shown in Figure 8-8. The drag box is pulled behind the paver by means of chains. This box may or may not have augers; for quick set systems augers should be used. The slurry seal should be easy to work and spread, and not cause any hang-up in the box.

The design mix is proportioned by weight while the slurry surfacing machines deliver materials by volume. Due to this different nature of the measurements, it is essential that calibration be done with the actual job materials. No machine should be allowed to work on a Caltrans job without a proper calibration.

Figure 8-7 Slurry Surfacing Machine

Figure 8-8 Slurry Seal Box with Augers

8.5.3 Stockpile / Project Staging Area Requirements

The stockpile and project staging area must meet some basic requirements. These requirements include:

- A clean, well-drained pad for aggregate piles
- A front-end loader for loading machines or Flow Boy-type vehicles in continuous operation
- A salt-free water supply
- An emulsion tanker
- An additive tanker

The stockpile and staging area should be as close as possible to the job site. Figure 8-9 illustrates a typical stockpile and staging area.

Figure 8-9 A Typical Stockpile and Project Staging Area

Operations should be scheduled to run as smoothly as possible and provide good traffic flow through the work zone. Aggregates that are below optimum moisture content specified in the mix recipes should be remixed using the front-end loader to avoid segregation. In some cases aggregates that are separating in the stockpile or during loading may need to be sprayed with water to avoid fines loss.

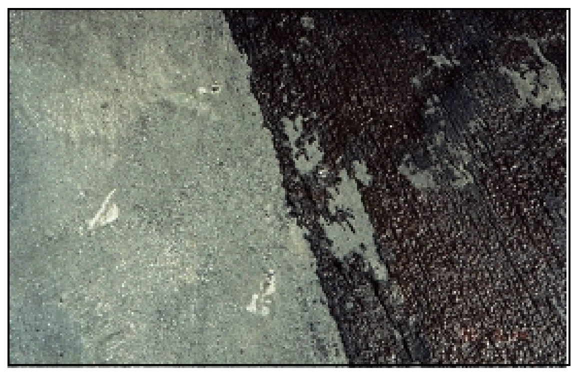
8.5.4 Surface Preparation

The main objective of surface preparation is to provide a clean and sound surface on which the microsurfacing is applied. The first step of surface preparation is to restore the pavement's structural integrity and functional performance characteristics through crack sealing and patching (see Chapters 4 and 5 of this guide for more information on these procedures).

Immediately before the slurry surfacing is applied, the road must be swept clean of all debris including clay and hard-to-remove materials (such as organic matter). High power pressure washing may be required. If left on the road, these types of contaminants will cause delamination of the treatment in these areas. Thermoplastic road markings must also be removed prior to placing a slurry surface, or at least abraded to produce a rough surface. Paint markings require no pretreatment. Rubber crack sealant on the roadway should be removed prior to applying a slurry surface.

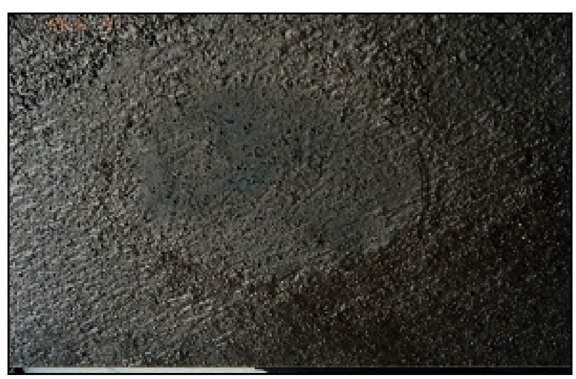
Utility inlets should be covered with heavy paper or roofing felt adhered to the surface of the inlet. The paper is removed once the slurry surfacing has sufficiently cured. In addition to covering the inlets, all starts, stops, and handwork on turnouts should be done on roofing felt to ensure sharp, uniform joints and edges. Figure 8-10 illustrates the various surface preparation steps along with illustrations of delamination resulting from poor surface preparation.

a) Sweeping



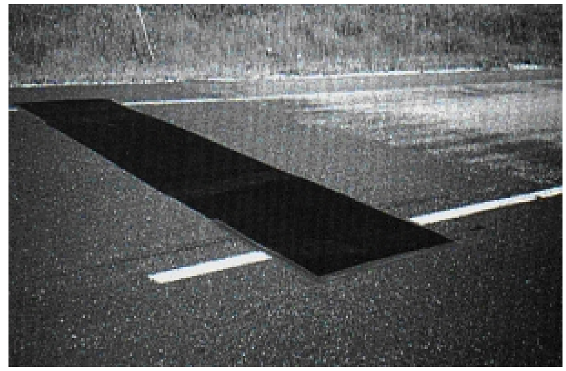
b) Dirty surfaces Result in Poor Adhesion (Delamination)

c) Cover Utilities with Kraft Paper



d) Slurry Covers Inlet and Paper Cover

e) Peel Off Paper Covering Once Treatment has Cured



f) Starting Transverse Joints on Roofing Felt Produces Clean Joints

Figure 8-10 Surface Preparation Methods

8.5.5 Application Conditions

The application conditions required are addressed in detail in the Caltrans Standard Specifications Section 37 (Caltrans, 2006). The basic requirement for success is that the emulsion must be able to break and form continuous films, as it is the only way a slurry mixture can become cohesive. As a result, humidity, wind conditions, air and pavement surface temperature are important and need to be considered. Modifications to additives should be made according to the changing environment during application. In any case, application of a slurry seal is generally not suitable for night work. This is due to the lower evaporation rate at night, which results in longer breaking and curing times.

For a conventional slurry seal project, air temperature should be a minimum of 50°F (10°C) and rising. Humidity should be 60% or less and a slight breeze is advantageous. Work should not be started if rain is imminent. Slurry seals will typically resist rain induced damage after as little as one hour but typically require at least three hours to cure to a fully waterproof state. Additionally, breaking time for a slurry is affected by ambient temperature. Work should not be started if freezing temperatures are anticipated within 24 hours of construction. Aggregate and emulsion temperature are also affecting the breaking time. An example is given in Figure 8-11.

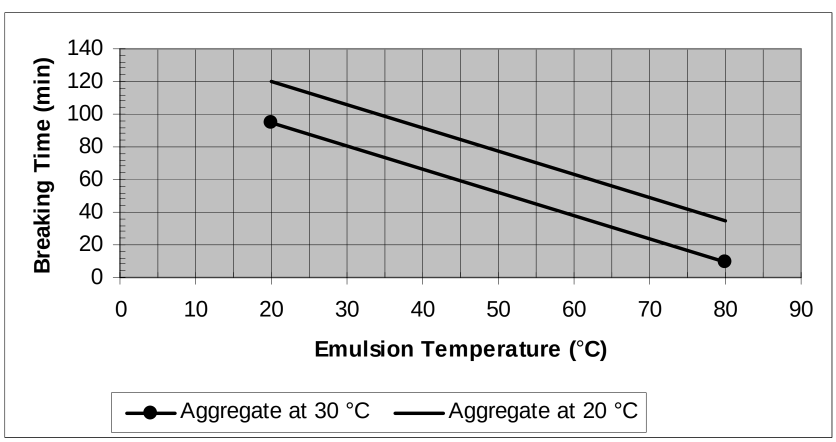


Figure 8-11 Effect of Temperature on Break Rate

8.5.6 Quality Issues

Quality control is critical during the constriction process to achieve a uniform surface finish. The main areas of concern are discussed below.

Longitudinal Joints

Longitudinal joints may be overlapped or butt jointed. They should be straight or curve with the traffic lane. Overlaps should not be in the wheel paths and should not exceed 3 in (75 mm) in width. Figure 8-12 illustrates high quality and poor quality longitudinal joints.

a) High Quality Longitudinal Joint

b) Poor Quality Longitudinal Joints

Figure 8-12 Longitudinal Joints

Transverse Joints

Transverse joints are inevitable when working with batch systems; every time a truck is emptied a transverse joint is required. Transitions at these joints must be smooth to avoid creating a bump in the surface. The joints must be butted to avoid these bumps and handwork should be kept to a minimum. The main difficulty in obtaining a smooth joint occurs as the slurry machine starts up at the joint. Some contractors tend to over wet (add too much water) to the mix at start-ups. This leads to poor texture and scarring at the joints. Starting transverse joints on roofing felt can eliminate these problems. Figure 8-13 illustrates high quality and low quality transverse joints.

a) High Quality Transverse Joint

b) Low Quality Transverse Joint

Figure 8-13 Transverse Joints

Edges and Shoulders

Slurry sealed edges and shoulders can be rough and look poor. The edge of the spreader box should be outside the line of the pavement and edge boxes should be used when shoulders are covered. Figure 8-14 illustrates high quality and poor quality edge and handwork.

a) High Quality Edges and Shoulder

b) Poor Quality Edges and Shoulder

Figure 8-14 Edges and Shoulders

Uneven Mixes and Segregation

Poorly designed slurry mixtures or mixtures with low cement content or too high a water content may separate once mixing in the box has ceased. This leads to a black and flush looking surface with poor texture. Separated mixes may lead to a “false slurry” where the emulsion breaks onto the fine material. In such instances delamination may occur, resulting in premature failure. These types of mixes can be recognized as non-uniform mixes that appear to be setting very slowly. Figure 8-15 illustrates segregation and delamination resulting from a false slurry.

a) Segregation

b) Delamination from a False Slurry

Figure 8-15 Poor Mixes

Smoothness Problems

Slurry mixtures follow the existing road surface profile and thus do not have the ability to significantly change the pavement's smoothness. However, when using stiffer mixes the spreader box may, if incorrectly set up, chatter or bump as the material is spread and produce a washboard effect. The chattering may be addressed by making the mixture slower to set, adjusting the rubbers on the box, or adding weight to the back of the spreader box. Figure 8-16 illustrates the washboard effect.

Figure 8-16 Wash Boarding Effect

Damage Caused by Premature Reopening to Traffic

The slurry seal must build sufficient cohesion to resist abrasion due to traffic. Early stone shedding is normal, but should not exceed 3%. If a mixture is reopened to traffic too early it will ravel off quickly, particularly in high stress areas. It is important that the mixture has formed adequate cohesion before it is opened. Choosing the right time to reopen a surface to traffic is based largely on experience. However, a general rule of thumb for a slurry seal is that it can be opened when it has turned black. Figure 8-17 illustrates raveling caused by premature opening to traffic.

Figure 8-17 Traffic Damage Caused by Early Trafficking

8.5.7 Post Construction Conditions

Emulsion systems do not lose all water in the first hours after placement; the total water loss process can take up to several weeks. During this period the surface will be water resistant; however, if the water freezes, it can cause rupture of the binder film and subsequent raveling. For this reason, projects should not be started without a 2-week window when freezing weather will not occur.

Asphalt emulsion based systems cannot re-emulsify; however, if not fully cured, these systems can be tender enough to re-disperse under the effects of traffic loading and excessive water, especially ponding water. In this process, broken aggregates or asphalt particles that have not fully coalesced into films are dispersed in water, which disintegrates the emulsion. Thus, while light rain 3 hours after placing a slurry seal is acceptable, heavy rain coupled with heavy traffic will likely lead to surface damage, especially in high shear areas. Figure 8-18 illustrates damage caused by a combination of heavy rain and high shear (e.g., turning movement).

Figure 8-18 Damage Due to Post Application Heavy Rain with Shear

8.5.8 Post-Treatments

Rolling

Slurry seals will lose stone until the surface voids have been closed off, but it is acceptable for approximately 3% of surface stone to be lost. To limit the amount of loss, rolling with pneumatic rollers may be incorporated. For rut filling applications, rolling is almost always recommended. The roller should be light (6-7 tones maximum) and non-ballasted. One to two passes at a slow speed are recommended. This allows the water to be pressed to the surface, promoting evaporation and curing. Larger stones will be punched into the new surface, reducing early raveling. Figure 8-19 illustrates a typical roller operation.

Figure 8-19 Rolling a Slurry Surfacing

Sweeping

On heavily trafficked roads or where opening has lead to excessive stone loss, sweeping is essential. A suction broom is the best type of sweeper to use. Sweeping should be done just prior to opening to traffic and at periods determined by the level of stone loss. Figure 8-20 illustrates a suction broom.

Figure 8-20 Sweeping with a Suction Broom

Sanding

Sanding may be used to reduce the time that cross streets or intersections are closed. Sanding is the application of a fine layer of dry, washed sand that is broadcast over the slurry surface to prevent pickup. Sanding may also be used on wet spots. Sanding should not be done until the slurry can withstand walking traffic. Figure 8-21 illustrates the use of sanding at a cross street.

Figure 8-21 Sanding at a Cross Street

8.6 TROUBLESHOOTING AND FIELD CONSIDERATIONS

8.6.1 Troubleshooting Guide

This section provides information to assist the maintenance personnel in troubleshooting problems with slurry seals along with "dos and don'ts" that address common problems that may be encountered during the course of a project. The troubleshooting guide presented in Table 8-6 associates common problems to their potential causes. For example, an unstable emulsion, too little water in the mix, incompatibility between the emulsion and the aggregate, and so on, may cause a slurry surface to delaminate.

Table 8-6 Trouble Shooting Slurry Seal Job Problems

CAUSE	PROBLEM: Brown	Whitish	Won't Set	Poor Coating	Delayed Opening to Traffic	Breaks in Box	Ravels	Flushes	Delamination	Segregation
Emulsion										
Emulsion Unstable				•		•			•	
Emulsion too Stable	•		•		•		•			
Emulsion too hot						•				
Too Little Emulsion	•			•			•			
Too Much Emulsion								•		
Mix										
Too many fines				•		•	•			
Too much cement		•				•				
Too little cement			•		•		•			•
Too little additive				•		•	•			
Too much additive		•	•		•		•			
Too much water	•		•		•		•	•		•
Too little water		•		•		•	•		•	
Aggregate/emulsion not compatible			•	•	•		•		•	•
Conditions										
Too hot	•			•		•	•	•		
Too cold			•		•		•		•	
Rain	•		•	•	•		•	•	•	
High humidity		•	•							
Surface										
Fatty (Oily)			•					•		

In addition to the troubleshooting guide, Table 8-7 lists some commonly encountered problems and their recommended solutions.

Table 8-7 Common Problems and Related Solutions

PROBLEM	SOLUTION
UNEVEN SURFACE – WASH BOARDING	• Ensure the spreader box is correctly set up. • Ensure the viscosity of the mix is not too high. • Make adjustments so that the mix does not break too fast. • Wait until the ambient temperature is lower. • Use water sprays on the front of the spreader.
POOR JOINTS	• Reduce the amount of water at start up. • Use water spray if runners of spreader box are running on fresh material.
EXCESSIVE RAVEL	• Add cement and reduce additive so that the mix breaks and cures faster. • Check aggregate to ensure the clay fines are not too high. • Control traffic longer and at low speeds. • Wait until fully cured before allowing traffic. • Wait until mix is properly set before brooming or opening to traffic.

8.6.2 Field Considerations

The following tables are guides to the important aspects of performing a slurry surfacing project. The tables list items that should be considered in order to promote a successful job outcome. The answers to these questions should be determined, as required, before, during, and after construction. The appropriate staff to do this will vary by job type and size. Some topics may need attention from several staff members. The field supervisor should be acquainted with its contents.

The intention of the table is not to form a report but to bring attention to important aspects and components of the slurry surfacing project process. Some information is product specific and contained in the relevant standard specifications, special standard provisions, or special provisions.

PRELIMINARY RESPONSIBILITIES	
PROJECT REVIEW	• Is the project a good candidate for slurry surfacing? • What is the depth and extent of any rutting? • How much and what type of cracking exists? • Is crack sealing needed? • How much bleeding or flushing exists? • Is the pavement raveling? • What is the traffic level? • Is the base sound and well drained? • Review project for bid/plan quantities.
DOCUMENT REVIEW	• Bid Specifications • Mix Design Information • Special Provisions • Construction Manual • Traffic Control Plan (TCP)
MATERIALS CHECKS	• Has a full mix design and compatibility test been completed? • Is the binder from an approved source (if required)? • Has the binder been sampled and submitted for testing? • Does the aggregate meet all specifications? • Is the aggregate clean and free of deleterious materials? • Is the aggregate dry? • Is the emulsion temperature within application temperature specifications?

PRE-SEAL INSPECTION RESPONSIBILITIES	
SURFACE PREPARATION	• Is the surface clean and dry? • Have all pavement distresses been repaired? • Has the existing surface been inspected for drainage problems?
EQUIPMENT INSPECTION CONSIDERATIONS	
BROOM	• Are the bristles the proper length? • Can the broom be adjusted vertically to avoid excess pressure?
SLURRY SEAL EQUIPMENT	• Has each machine been calibrated with the project's aggregate and emulsion? • Who carried out calibration and what documentation has been provided? • Is the machine fully functional? • Has the machine been calibrated for this project's aggregate and certified. Is the spreader rubber clean and not worn? • Is the texture rubber clean and set at the right angle? • Are all paddles in the pug mill intact? • Is the spreader box clean?
ROLLERS (IF USED)	• Do the roller tire pressures comply with the manufacturer's specification? • What type roller will be used on the project (pneumatic-tired roller recommended)? • Do the roller tire size, rating, and pressures comply with manufacturer's recommendations? • Is the pressure in all tires the same? • Do all tires have a smooth surface?
STOCKPILE	• Is the stockpile site well drained and clean? • Does the Contractor have all of the equipment required at the stockpile site (loaders, tankers, and so on)?

EQUIPMENT INSPECTION CONSIDERATIONS	
EQUIPMENT FOR CONTINUOUS RUN OPERATIONS	• Is all equipment free of leaks? • Are “Flow Boys” or other nurse units clean and functional? • Are there enough units to allow continuous running with minimal stops for cleaning box rubbers?
SITE CONSIDERATIONS	
WEATHER REQUIREMENTS	• Have air and surface temperatures been checked at the coolest location on the project? • Do air and surface temperatures meet agency requirements? • Are adverse weather conditions expected? High temperatures, humidity, and wind will affect how long the emulsion takes to break. • The application of the slurry surfacing does not begin if rain is likely? • Are freezing temperatures expected within 24 hours of the completion of any application runs?
TRAFFIC CONTROL	• Do the signs and devices used match the traffic control plan? • Does the work zone comply with Caltrans requirements? • Flaggers do not hold the traffic for extended periods of time? • Unsafe conditions, if any, are reported to a supervisor (contractor or agency)? • The pilot car leads traffic slowly, 24 mph (40 kph) or less? • Signs are removed or covered when they no longer apply?
APPLICATION CONSIDERATIONS	
DETERMINING APPLICATION RATES	• Have agency guidelines and requirements been followed? • Have rut filling and leveling course application rates been calculated or estimated separately? • Has a full mix design been done? • Is more material applied to dried-out and porous surfaces? • Is more material applied on roads with low traffic volumes? • Is less material applied to smooth, non-porous, and asphalt-rich surfaces? • Has moisture content been adjusted in the application rate?

PROJECT INSPECTION RESPONSIBILITIES	
SLURRY SURFACING APPLICATION	• Has a test strip been done and is it satisfactory? • Have field tests been carried out and are the results within specification? • Are enough trucks on hand to keep a steady supply of material for the slurry machine? • Does the application start and stop with neat, straight edges? Will an edge box be used? • Does the application start and stop on building paper or roofing felt? • Are drag marks present due to oversize aggregate or dirty rubbers? • Are rubbers cleaned regularly and at the end of each day? • Does the machine take a straight, even line with minimal numbers of passes to cover the pavement? • Is the mix even and consistent? • Are fines migrating to the surface? • Is the application stopped as soon as any problems are detected? • Does the application appear uniform? • Does the surface have an even and uniform texture? • Is the application rate checked based on amounts of aggregate and emulsion used? • What is the time between spreading, foot traffic, and opening to vehicular traffic?
ROLLING	• Does rolling wait until the mat is stable? Roller is 5-6 tonnes (Caltrans, 1999b) maximum. • Is the entire surface rolled only once? • Do the rollers travel slowly, 5 mph (8-9 kph) maximum?
TRUCK OPERATION	• Are trucks staggered across the fresh seal coat to avoid driving over the same area? • Do trucks travel slowly on the fresh seal? • Are stops and turns made gradually? • Do truck operators avoid driving over the new slurry? • Do truck operators stagger their wheel paths when backing into the paving unit?
LONGITUDINAL JOINTS	• Is the meet line overlapped a maximum of 3 in (75 mm)? • Do the spreader box runners avoid running on fresh mat? • Are the meet lines made at the center of the road, center of a lane, or edge of a lane not in the wheel paths?

PROJECT INSPECTION RESPONSIBILITIES	
TRANSVERSE JOINTS	• Do all applications begin and end on building paper or roofing felt? • Mixture is not too wet at start up? • Is the building paper or roofing felt disposed of properly?
BROOMING	• Does brooming begin after the slurry surfacing can carry traffic? • Does brooming dislodge the slurry surfacing? • Is the surface raveling? Follow-up brooming should be done if raveling is high or if traffic is high.
OPENING THE SLURRY SURFACING TO TRAFFIC	• Does the traffic travel slowly — 24 mph (40 kph) or less—over the fresh slurry surfacing? • Are reduced speed limit signs used when pilot cars are not used? • After brooming, have pavement markings been placed before opening to traffic? • Have all construction-related signs been removed when opening to normal traffic?
CLEAN UP	• Have all loose aggregate from brooming been removed from traveled way prior to opening to traffic? • Have all binder spills been cleaned up?

8.7 REFERENCES

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CHAPTER 9 MICRO-SURFACING

9.1 OVERVIEW

This chapter provides an overview of the micro-surfacing products presently used in California, including materials and specifications, mix design, project selection, details regarding construction, a troubleshooting guide to assist the Engineer if problems arise during the placement of these mixtures, and a list of suggested field considerations when placing a micro-surfacing.

9.1.1 General Description

Micro-surfacing is a mixture of asphalt emulsion, graded aggregates, mineral filler, water and other additives. The mixture is made and placed on a continuous basis using a travel paver (Slurry Surfacing Machine). The travel paver meters the mix components in a predetermined order into a pug mill. The typical mixing order is aggregate followed by cement, water, the additive and the emulsion. Figure 9-1 illustrates the process of slurry surfacing.

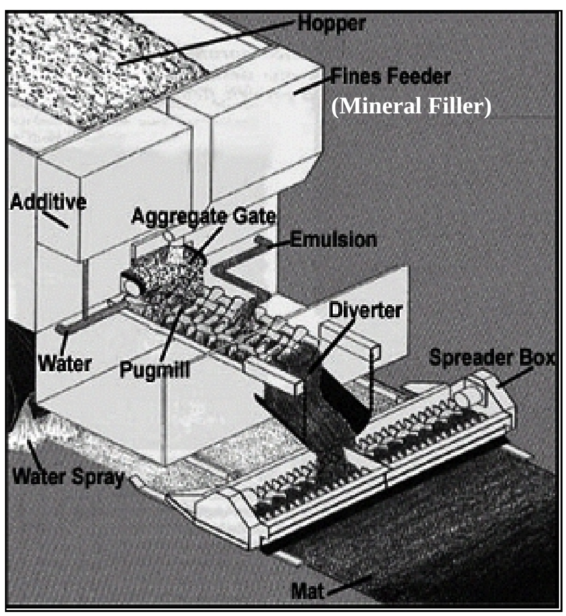


Figure 9-1 Schematic of a Slurry Surfacing Machine (Holleran, 2001)

The resulting slurry material is a free flowing composite material that is spread via a spreader box over the existing road surface. The consistency of the slurry material allows it to spread over the pavement, wetting it, and forming an adhesive bond to the pavement.

The slurry mixture contains asphalt emulsion that breaks onto the pavement surface through heterogeneous or homogenous flocculation. The asphalt particles coalesce into films, creating a cohesive mixture. The mixture then cures, by loss of water, into a hardwearing, dense-graded asphalt/aggregate mixture that is bonded to the existing pavement.

A slurry surfacing does not add any structural capacity to an existing pavement; they are applied as a maintenance treatment to improve the functional characteristics of the pavement surface. The types of slurry surfacing and the pavement characteristics they improve are discussed next.

9.1.2 Types of Slurry Surfacing

There are two main types of slurry surfacing in common use. These include:

- Slurry Seal
- Micro-surfacing

Currently, Caltrans uses slurry seals routinely, while micro-surfacing is still in the pilot stages of assessment.

Micro-surfacing is a thin surfacing, and can be laid at two to three times the thickness of the largest stone in the grading. The emulsion in the system is always polymer modified and special additives are used to create a chemical break that is largely independent of weather conditions. In breaking, the emulsion forces water from the aggregate surface. Such systems can often be opened to traffic within 1 hour or less of its application under a range of conditions (Holleran, 2001a).

Micro-surfacing can be used for the same applications as slurry seals. However, micro-surfacing uses better quality aggregates and a fast setting emulsion of higher stiffness allowing thicker layers to be placed.

These aspects create the following extended performance characteristics and applications for micro-surfacing:

- Correction of Minor Surface Profile Irregularities
- Rut Filling
- Higher Durability
- Ability to be Placed at Night or in Cooler Temperatures

Micro-surfacing, like slurry seal, is not intended as a crack treatment and will not prevent cracks in the underlying pavement from reflecting through to the surface. Micro-surfacing does not add any structural capacity to an existing pavement; it is applied as a maintenance treatment to improve the functional characteristics of the pavement surface.

9.2 MATERIALS

The main materials used in micro-surfacing are:

- Asphalt Emulsion with Polymer Modification
- Water
- Aggregate
- Mineral Filler
- Additives

9.2.1 Asphalt Emulsion

Asphalt emulsions are defined in Chapter 2 of this advisory guide as dispersions of asphalt in water stabilized by a chemical system. In the case of slurry surfacing systems (like slurry seal and micro-surfacing), the emulsion may be cationic or anionic; however, cationic emulsions are the most common. Caltrans Standard Specifications Section 94 (Caltrans, 2006) provides specifications for the main emulsion types. However, only polymer-modified (PM), quick-set (QS) emulsions are used in micro-surfacing. Common polymer modified quick setting emulsions include:

- PMCQS-1h
- PMQS-1h
- MSE (Micro-surfacing emulsion) (Caltrans, 2002)

These emulsions are specially formulated for compatibility with the aggregate and to meet the appropriate mix design parameters. Specifications for these emulsions are not included in the Standard Specifications (Caltrans, 2006). Unlike slurry seal, micro-surfacing is still being researched by Caltrans and the specification is under development. The Caltrans Micro-surfacing Pilot Study carried out in 2001 was the first step in the process of implementing micro-surfacing to the Department. A non-standard specification has been developed under this study and it is referred to as the MSE emulsion. In reality, the MSE emulsion is a polymer-modified quick-set emulsion (Caltrans, 2002).

Emulsion specifications are based on standard emulsion characteristics, such as stability, binder content, and viscosity. In all micro-surfacing systems, polymer is added to the emulsion. The polymer enhances stone retention, especially in the early life of the treatment. The added polymer also reduces thermal susceptibility. Polymers also improve softening point and flexibility, which enhance the treatment's crack resistance and, in the case of micro-surfacing, allow thicker sections (two to three stones thick) to be placed. Thicker sections allow micro-surfacing to be used for rut filling. Generally, micro-surfacing and slurry seal mixtures with a polymer-modified emulsion do not impart significant resistance to reflective cracking.

Emulsions are usually modified with latex, which is an emulsion of rubber particles. The latex does not mix with the asphalt; rather, the latex and the asphalt particles intermingle to form a 3-D structure, as illustrated in Figure 9-2. The latex used is either neoprene or styrene butadiene styrene (SBR) for slurry seal. Micro-surfacing is modified with either natural latex or SBR latex. When modified with latex, slurry seal emulsions are referred to PMCQS-1h or, more commonly, LMCQS-1h where "LM" stands for "latex-modified" (Holleran, 2001).

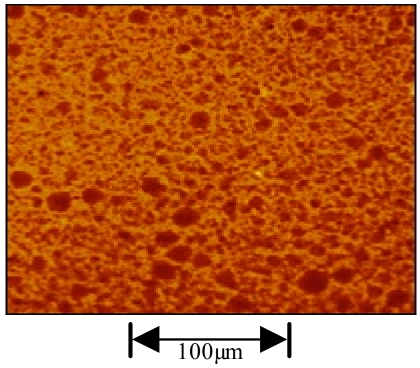


Figure 9-2 Micrograph of a Latex/Asphalt Cured Film (Holleran, 2002)

The main emulsions used for micro-surfacing in California are latex modified CQS-1h type emulsions and micro-surfacing emulsion (MSE) (Holleran, 2001, Caltrans, 2002).

Latex may separate from the emulsion due to the differences in density. If separation occurs, the latex must be remixed into the emulsion by circulation in the tanker before the modified emulsion is transferred to the slurry machine for application (Holleran, 2002).

Basic emulsion requirements are shown in Table 9-1. Key requirements include the binder content and residual properties. The viscosity is of importance as is the storage stability to ensure that the emulsion can be used effectively in the field.

Table 9-1 Typical Emulsion Properties for Micro-surfacing and Polymer Modified Slurry Quick Set (Caltrans, 2002, Holleran, 2002)

Tests on Emulsion	Typical Specification	Method
Viscosity, SSF @ 25°C, sec	15 – 90	AASHTO T 59
Settlement, 5 days, %	< 5	ASTM D 244
Storage Stability, 1 day, %	< 1	AASHTO T 59
Sieve Test, %	< 0.30	AASHTO T 59
Residue by Evaporation, %	> 62	California Test 331
Tests on Residue from Evaporation Test	**Typical Specification**	**Method**
Penetration, 25°C	40 – 90	AASHTO T 49
Softening Point, °C	> 57	AASHTO T 53
G* @ 20°C, 10 rad/sec, MPa	Report Only	AASHTO TP 5
Phase Angle @ 50°C, 10 rad/sec, PA(max) – PA base	Report Only	AASHTO TP 5
Stiffness @ -12°C, MPa M-Vlaue	Report Only	AASHTO TP 1
Torsional Recovery, %	> 18% (LMCQS-1h)	California Test 332
Polymer Content	> 2.5% (LMCQS-1h)	California Test 401

9.2.2 Aggregates

The aggregate's key physical characteristics for suitable incorporation into a slurry surfacing mix are defined by:

- **Geology:** This determines the aggregate's compatibility with the emulsion along with its adhesive and cohesive properties.
- **Shape:** The aggregates must have fractured faces in order to form the required interlocking matrix (Holleran, 2001). Rounded aggregates will result in poor mix strength.
- **Texture:** Rough surfaces form bonds more easily with emulsions.
- **Age and Reactivity:** Freshly crushed aggregates have a higher surface charge than aged (weathered) aggregates. Surface charge plays a primary role in reaction rates.
- **Cleanliness:** Deleterious materials such as clay, dust, or silt can cause poor cohesion and adversely affect reaction rates.
- **Soundness and Abrasion Resistance:** These features play a particularly important role in areas that experience freeze-thaw cycles or are very wet.

Two gradations are specified for micro-surfacing; namely, Type II and Type III (Caltrans, 2002). The gradation for each type is listed in Table 9-2.

Table 9-2 Caltrans Slurry Surfacing Aggregate Gradings (Caltrans, 1999a)

SIEVE SIZE	PERCENTAGE PASSING	
	TYPE II	TYPE III
3/8 in (9.5mm)	100	100
No. 4 (4.75 mm)	94-100	70-90
No. 8 (2.36 mm)	65-90	45-70
No. 16 (1.18 mm)	40-70	28-50
No. 30 (600-µm)	25-50	19-34
No. 200 (75-µm)	5-15	5-15

The primary difference among these gradations is the aggregate top size. This dictates the amount of residual asphalt required by the mixture and the purpose to which the micro-surfacing is most suited. Type II micro-surfacing is coarser and is suggested for urban and residential streets and airport runways. Type III micro-surfacings have the coarsest grading and are appropriate for filling minor surface irregularities (micro-surfacing only), correcting raveling and oxidation, and restoring surface friction. Type III micro-surfacings are typically used on arterial streets and highways.

The role of fines (i.e., aggregate particles No. 200 [75 µm] and finer) in a slurry surfacing mix is to form a mortar with the residual asphalt to cement the larger stones in place. The fines content is essential for creating a cohesive hardwearing mix. Generally, the fines content should be at the mid-point of the grading envelope. Recent work suggests that the distribution of the sub-No. 200 (75 micron) fraction is critical to control the reaction rate in micro-surfacing emulsions (Schilling, 2002). The general aggregate quality requirements for the various slurry systems are listed in Table 9-3.

Table 9-3 General Aggregate Properties (Caltrans, 1999a, Caltrans, 2002) and Aggregate Requirements (Schilling, 2002)

TEST	MICRO-SURFACING	TEST # AND PURPOSE
Sand Equivalent (min)	65	CT 217 (Clay Content)
Durability Index (min)	65	CT 229 (Resistance to wet/dry exposure)
Abrasion (LA Rattler) 500rev	35% max	ASTM 211 (Resistance to traffic)
Crushed Particles	95%	CT 205

9.2.3 Mineral Filler and Additives

In most slurry surfacing systems, cement is used as a mixing aid allowing the mixing time to be extended and creating a creamy consistency that is easy to spread. Additionally, hydroxyl ions counteract the emulsifier ions, resulting in a mix that breaks faster with a shorter curing time. Cement is also a fine material and, as such, absorbs water from the emulsion, causing it to break faster after placement. Fine materials, as previously discussed, also promote cohesion of the mixture by forming a mortar with the residual asphalt.

Additives other than cement vary and are features of particular systems. They can act as retardants to the reaction with emulsions, either as a prophylactic, slowing the emulsifier's access to the aggregate surface, or by preferentially reacting with the emulsifier in the system. Additives include emulsifier solutions, aluminum sulfate, aluminum chloride, and borax. Generally, increasing the concentration of an additive slows the breaking and curing times. This is useful when air temperatures increase during the day.

9.3 MIX DESIGN

The performance of a micro-surfacing depends on the quality of the materials and how they interact during cure and after cure. The mix design procedure looks at the various phases of this process, which include:

- **Mixing:** Will the components mix together and form true, free flowing slurry?
- **Breaking and Curing:** Will the emulsion break in a controlled way on the aggregate, coat the aggregate, and form good films on the aggregate? Will the emulsion build up cohesion to a level that will resist abrasion due to traffic?
- **Performance:** Will the micro-surfacing resist traffic-induced stresses?

The steps in micro-surfacing design include:

- Prescreening of Materials
- Job Mix Design
- Final Testing

At each stage, mixing, breaking, curing, and performance issues are addressed.

9.3.1 Prescreening

Prescreening involves testing the physical properties of the raw materials. The emulsion type is selected based on job requirements and is checked against the requirements laid out in the specifications (Table 9-1). The aggregate is checked against specifications (Tables 9-2 and 9-3) and a simple mixing test is performed to assess compatibility with the emulsion. When both of these steps are satisfied, the job mix formula can be developed. During the overall process the materials may be changed at any time until satisfactory results are obtained.

9.3.2 Job Mix Design

Mixing Proportions

The International Slurry Surfacing Association (ISSA) test method detailed in Technical Bulletin 102 is normally used to determine the approximate proportions of the slurry mix components (ISSA, 1990). In this test which is typically conducted by the testing lab, a matrix of mix recipes are made up and the manual mixing time is recorded for each mixture. A minimum time is required to ensure that the mixture will be able to mix without breaking in the slurry machine. At this stage, phenomena such as foaming and coating are visually assessed. Also at this stage, the water content and additive content can be determined to produce a quality mixture. Figure 9-3 illustrates a good slurry mixture consistency which meets the requirements of Caltrans non standard special provision (NSSP) 37-600.

Figure 9-3 Good Mixture Consistency

The mixing time must be at least 120 seconds for micro-surfacing at 77°F (25°C). The process may be repeated at elevated or reduced temperatures to simulate expected field conditions at the time of application. The best mix is chosen, based on good coating of mixing times in excess of the minimum required through the entire range of expected application temperatures.

Cohesion Build-up

Once the emulsion content is determined, three mixes are then made, one at the selected emulsion percentage from above, one at -2% of the selected emulsion content and one at +2% of the selected emulsion content. This allows a bracketing of the desired mix proportions. The ISSA test method TB 139 (ISSA, 1990) is used to determine the cohesion build-up in a slurry mixture. This test may be performed at the expected field temperatures to provide the most accurate estimate of the treatment's characteristics. Table 9-4 lists mix requirements for micro-surfacing.

Abrasion Resistance (Wet Track Abrasion Test – WTAT)

Mixes are made at three emulsion contents, optimum, optimum +2%, and -2% of optimum. These mixes are then cured in circular molds for 16 hours at 140°F (60°C). The samples are then soaked for either 1 hour or 6 days, depending on the abrasion test (TB 100) (ISSA, 1990) and the material. Slurry design requires a 1-hour soaking while micro-surfacing requires 1-hour and 6-day soaking periods. After soaking, a standard rubber hose is ground over the surface of the sample (while still submerged) for a set period of time. The wear loss is then calculated. The test equipment is shown in Figure 9-4, while the abrasion resistance requirements are listed in Table 9-4.

The results of the abrasion test are plotted along with the specification requirements. This allows selection of the minimum binder content of the mixture.

a) Mixer Equipped with sample Mold and Rubber Hose Attachment

b) Orbital Grinding of Sample Using Rubber Hose Attachment

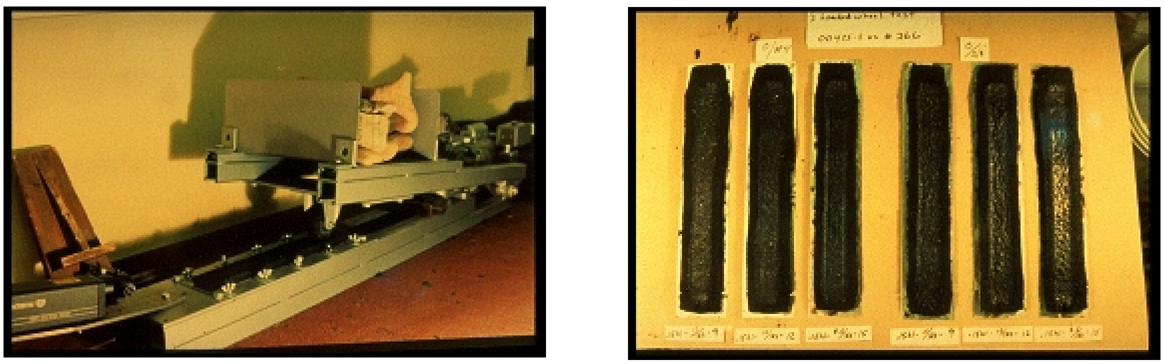
Figure 9-4 Wet Track Abrasion Test Apparatus and Test in Progress (Holleran, 2001)

Table 9-4 Typical Mix Requirements (Caltrans, 2002, ISSA, 2005)

PROPERTY	TEST	MICRO-SURFACING
Wear Loss (Wet Track Test)	TB 100 (1 hr soak) (6 day soak)	0.11 lb/ft^2 (540 g/m^2) max 0.16 lb/ft^2 (800 g/m^2) max
Traffic Time (Wet Cohesion Test)	TB 139 (30 minutes) (60 minutes)	0.87 lb-ft (0.12 kg-m) min 1.4 lb-ft (0.20 kg-m) min
Adhesion (Wet Strip) Integrity SB	TB 114 TB 144	>90% 11 pts min (AAA, BAA)
Excess Binder	TB 109	0.11 lb/ft^2 (540 g/m^2) max
Deformation	TB 147	10% max

Upper Binder Limit

The upper binder limit is determined using the Loaded Wheel Test, as described in TB 109 (ISSA, 1991). In this test, the slurry seal specimen is compacted by means of a loaded rubber tired reciprocating wheel as illustrated in Figure 9-5. After 1000 loading cycles, the specimen is removed from the machine, washed and dried to constant weight. Then, the specimen is mounted again on the machine and hot sand is added on the surface. After another 100 cycles of compaction, the increase in weight of the specimen due to sand adhesion is noted. This provides a measure of the free asphalt on the surface of the sample. The more prone the mix is to flushing or bleeding under traffic loading the larger the amount of sand retained on the specimen. Figure 9-5 illustrates the test apparatus along with a series of tested samples.



a) Testing Apparatus b) Tested Samples Showing Retained Sand

Figure 9-5 Loaded Wheel Test and Excess Asphalt Test Apparatus and Test Samples

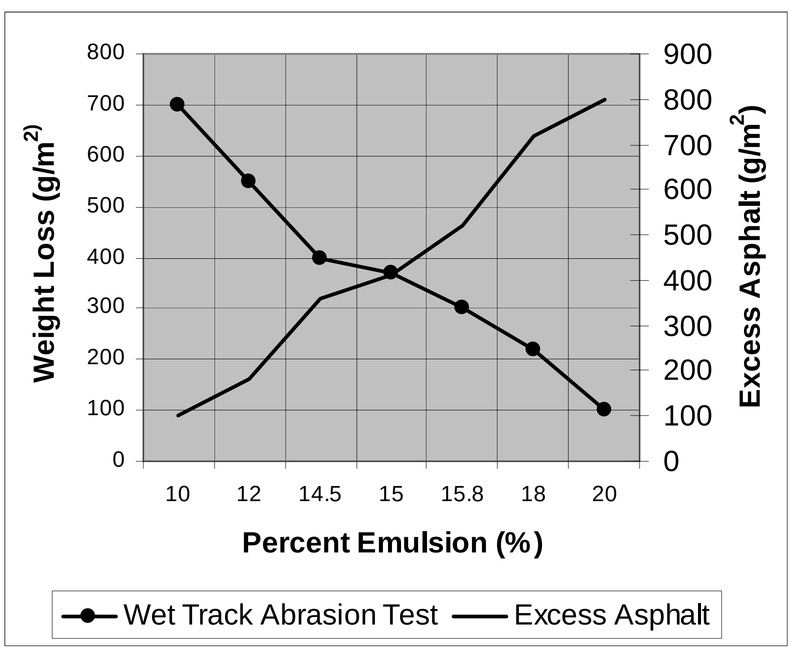


Figure 9-6 Determining Optimum Binder Content

Optimum Binder

The optimum percentage emulsion or binder content is found by plotting the results obtained from the Wet Track Test (TB 100) and the Excess Binder Test (TB 109) (ISSA, 1990). Figure 9-6 illustrates a typical plot of test results. The optimum binder content is close to the intersection of the two plotted lines, but the testing does not account for all the factors influencing the mix. For example, the optimum binder content at the intersection of the plotted results is adjusted for the expected traffic conditions. A rule of thumb is to select the highest binder content that passes both tests for low traffic conditions and the lowest binder content for heavy traffic conditions. Note that this requires an experienced designer to select the optimum and this must be based on field knowledge and experience. This is a weakness in the current design process.

9.3.3 Final Testing

Once the job mix components have been selected, the mix is tested to determine its properties and ensure compliance with the specifications listed in Table 9-4. If the mix conforms to the specifications, the emulsion content and aggregate grading is reported as the job mix formula.

Field adjustments may be made to the job mix formula to accommodate climatic variables during application. As a result of the mix design process, adjustments are limited to the amount of additives (cement and retardant) and water content required to ensure a good homogeneous mix at the time of application.

9.4 PROJECT SELECTION

9.4.1 Distress and Application Considerations

Slurry surfacing may be used for a range of applications, but job selection is critical and often pretreatments such as pothole patching crack sealing, and dig outs are required. Table 9-5 lists general job selection criteria for slurry surfacing treatments and typical application rates.

Table 9-5 Job Selection Criteria

APPLICATIONS	AGGREGATE TYPE	
	II	III
Void Filling	●	
Wearing Course (AADT) < 100	●	
Wearing Course (AADT) 100 – 1,000	●	●
Wearing Course (AADT) 1,000 – 20,000	●	●
Minor Shape Correction (0.4-0.8 in [10-20mm])		●
Application Rates in pounds of dry aggregate per square yard	10 – 15	20 – 25

The main use of micro-surfacing materials is for pavement preservation as a part of a program of periodic surfacing before distresses appear. The main criteria for project selection are:

- Sound and well drained bases, surfaces, and shoulders.
- Free of distresses, including potholes and cracking. These must be repaired before slurry application. Potholes should be filled and compacted several weeks prior to slurry surfacing. Emulsion crack filling should be done several months prior to slurry surfacing.

Distress modes that can be addressed using micro-surfacing include:

- **Raveling:** Loose surfaces or surfaces losing aggregate may be resurfaced using slurry seals or micro-surfacing.
- **Oxidized pavement with hairline cracks:** These surfaces may be resurfaced using slurry seals or micro-surfacing.
- **Rutted pavements:** Deformation resulting from consolidation of the surfacing only. Rutting due to base failure of significant plastic deformation of the HMA cannot be treated except as a temporary measure.
- **Rough pavements with short wavelength:** These irregularities may be treated with micro-surfacing, provided the frequency of the irregularities is shorter than the spreader box width.

Distress modes that cannot be addressed using micro-surfacing include:

- **Cracking** (including reflection cracking)
- **Base Failures** of any kind
- **HMA Layers** that exhibit plastic shear deformation

Micro-surfacing will not alleviate the cause of these distresses. As a result, the distresses will continue to form despite the application of a slurry surfacing.

9.4.2 Performance of Micro-surfacing

Micro-surfacing performance is strongly affected by workmanship and the condition of the pavement at the time of application. When used as a preventive maintenance treatment, on pavements in relatively good condition, micro-surfacing may last 7 to 10 years (Van Kirk, 2000), although longer life times have been claimed (Van Kirk, 2000). On average however, the life expectancy of a micro-surfacing treatment is 5 to 7 years. When applied in ruts, the life of the treatment is dependant on the stability of the micro-surfacing, the traffic level, and the condition of the underlying pavement.

The main mechanism of failure is wear. Through wear the surface oxidizes and is abraded over time. Premature treatment failure occurs from placement on highly deflecting surfaces, cracked surfaces, pavements with base failures, and on dirty or poorly prepared surfaces (resulting in delamination).

9.5 CONSTRUCTION

The main components of the construction process include:

- Safety and Traffic Control
- Equipment Requirements
- Stockpile/Project Staging Area Requirements
- Surface Preparation
- Application Conditions
- Types of Applications

- Quality Issues
- Post Construction Conditions
- Post-Treatments

Sections 9.6.2 titled “Field Considerations”, provides a series of tables to guide project personnel through the important aspects of applying a slurry surfacing.

9.5.1 Safety and Traffic Control

Traffic control is required both for the safety of the traveling public and the employees performing the work. Traffic control should be in place before work forces and equipment enter onto the roadway or into the work zone. Traffic control includes construction signs, construction cones and/or barricades, flag personnel, and pilot cars to direct traffic clear of the maintenance operation. For detailed Traffic Control requirements please refer to the Caltrans project specifications and the Caltrans Code of Safe Operating Practice (Caltrans, 1999).

Traffic control is required to ensure that the slurry surfacing has had adequate time to cure prior to reopening to traffic. The curing time for the slurry surfacing material will vary depending on the pavement surface conditions and the weather conditions at the time of application. Additional traffic control considerations are listed in the Field Considerations section (Section 9.6.2).

9.5.2 Equipment Requirements

Modern equipment, as shown in Figure 9-7, can be used to place either slurry seal or micro-surfacing. Micro-surfacing materials can be delivered and placed at the job site using either a mixer-spreader truck or a continuous mixing machine. Use the continuous mixing machine on:

1. Freeways
2. Conventional highways or expressways when work totals over 2 lane miles in length and there are segments of 1 mile or greater, without sharp curves, that can be paved without interruption (i.e., few or no intersections or concrete bridge decks) and has areas where the machine can easily be turned around.

The difference between slurry and micro-surfacing equipment is in the spreader boxes used. A slurry seal spreader box is a drag box, as shown in Figure 9-8. The drag box is pulled behind the paver by means of chains. This box may or may not have augers; for quick set systems augers should be used. The slurry seal should be easy to work and spread, and not cause any hang-up in the box.

A micro-surfacing spreader box, shown in Figure 9-9, has to move a much stiffer mixture than a slurry spreader box, do it quickly, and then spread it before the emulsion breaks. To accommodate this, two sets of augers are used and a texturing rubber is added at the rear of the box. The texturing rubber is usually spread using an outrigger. The outrigger creates the desired surface texture for the surface. Additionally, a micro-surfacing box is rigidly attached to the rear of the paver, allowing a preset thickness of material to be placed.

Figure 9-7 Slurry Surfacing Machine

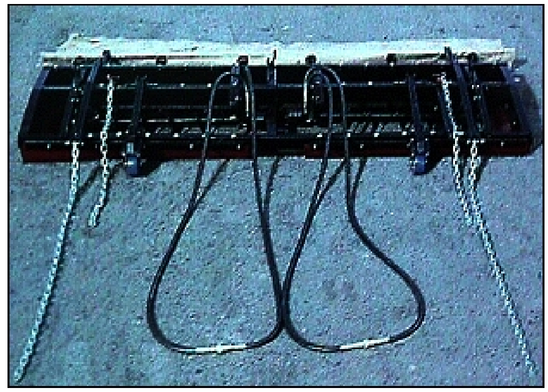
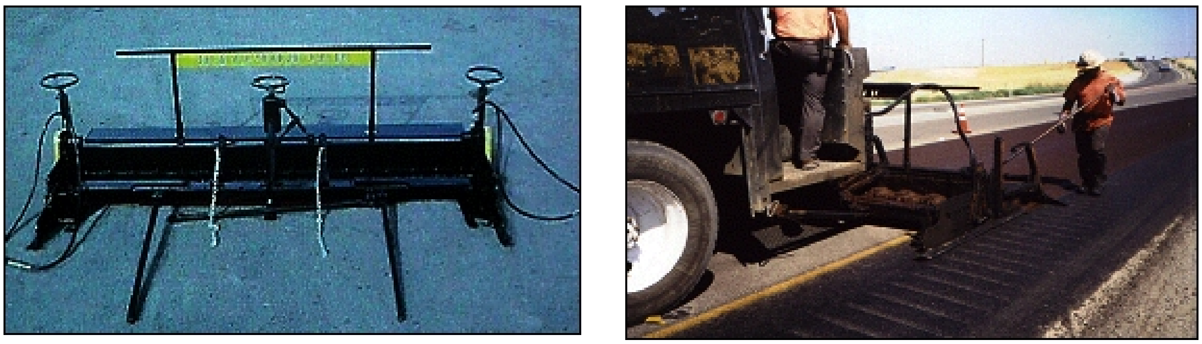


Figure 9-8 Slurry Seal Box with Augers



a) Typical Micro-surfacing Spreader Box

b) Outrigger Texture Flap

Figure 9-9 Micro-surfacing Equipment and Application

Rut Filling and Shoulder Equipment

Special boxes are used for rut filling applications when filling ruts greater than 0.5 in (12 mm) deep. When filling ruts less than 0.5 in (12 mm) deep, a steel strike-off box is used for the scratch courses (see Section below). Adjustable width edge boxes are used for shoulders and to create clean joints between shoulders and the traveled way. Figures 9-10 and 9-11 illustrate a rut filling box and an adjustable edge box, respectively.

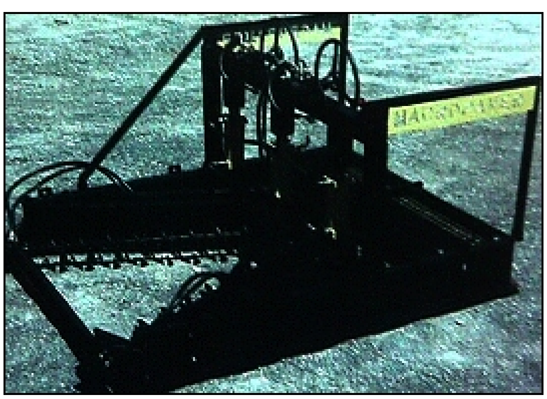


Figure 9-10 Rut Box

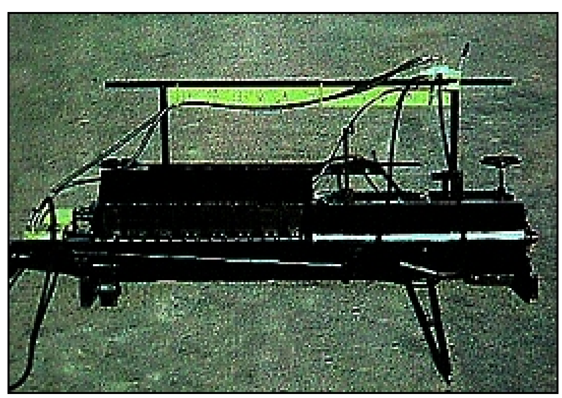


Figure 9-11 Adjustable Edge Box

Calibration

The design mix is proportioned by weight while the slurry surfacing machines deliver materials by volume. Due to this different nature of the measurements, it is essential that calibration be done with the actual job materials. No machine should be allowed to work on a Caltrans job without a proper calibration. Calibration requirements are discussed in the Department's Material Plant Quality Program (MPQP).

9.5.3 Stockpile / Project Staging Area Requirements

The stockpile and project staging area must meet some basic requirements. These requirements include:

- A Clean, Well-drained Pad for Aggregate Piles
- Front-end Loader for Loading Machines
- Flow Boy-type Vehicles in Continuous Operation
- A Salt-Free Water Supply
- An Emulsion Tanker
- An Additive Tanker

The stockpile and staging area should be as close as possible to the job site. Figure 9-12 illustrates a typical stockpile and staging area.

Figure 9-12 A Typical Stockpile and Project Staging Area

Operations should be scheduled to run as smoothly as possible and provide good traffic flow through the work zone. Aggregates that are measured to have moisture content below optimum should be remixed using the front-end loader to avoid segregation. In some cases aggregates that are separating in the stockpile or during loading may need to be sprayed with water to avoid fines loss.

9.5.4 Surface Preparation

The main objective of surface preparation is to provide a clean and sound surface on which the micro-surfacing is applied. The first step of surface preparation is to restore the pavement's structural integrity and functional performance characteristics through crack sealing and patching (Chapters 4 and 5).

Immediately before the micro-surfacing is applied, the road must be swept clean. If clay or hard-to-remove materials (such as organic matter) are present, high power pressure washing may be required. If left on the road, these types of contaminants will cause delamination of the treatment in these areas. Thermoplastic road markings must also be removed prior to placing micro-surfacing, or at least abraded to produce a rough surface. Paint markings require no pretreatment. Rubber crack sealant on the roadway should be removed prior to applying a slurry surface.

Utility inlets should be covered with heavy paper or roofing felt adhered to the surface of the inlet. The paper is removed once the slurry surfacing has sufficiently cured. In addition to covering the inlets, all starts, stops, and handwork on turnouts should be done on roofing felt to ensure sharp, uniform joints and edges. Figure 9-13 illustrates the various surface preparation steps along with illustrations of delamination resulting from poor surface preparation.

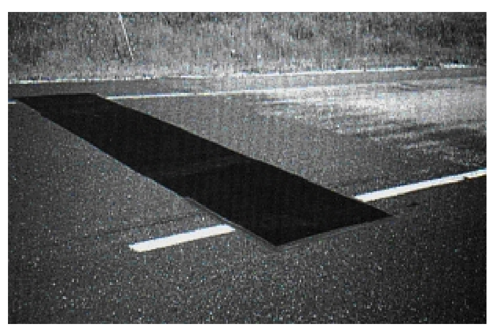
a) Sweeping

b) Dirty surfaces Result in Poor Adhesion (Delamination)

c) Cover Utilities with Kraft Paper

d) Micro-surfacing Covers Inlet and Paper Cover

e) Peel Off Paper Covering Once Treatment has Cured



f) Starting Transverse Joints on Roofing Felt Produces Clean Joints

Figure 9-13 Surface Preparation Methods

9.5.5 Application Conditions

The application conditions required are addressed in detail in the Caltrans "Micro-surfacing Pilot Study 2001", Appendix A (Caltrans, 2002). The basic requirement for success is that the emulsion must be able to break and form continuous films, as it is the only way a slurry mixture can become cohesive. As a result, humidity, wind conditions, and air and surface temperature are important and need to be considered. Modifications to additives should be made according to the changing environment during application. Because micro-surfacing slurry systems use a chemical break, they can be placed at night.

Micro-surfacing shall only be placed when the ambient temperature is 8°C (46°F) and rising and the high temperature for the day is expected to be at least 20°C. Micro-surfacing shall not be placed if rain is imminent or if the ambient temperature is expected to fall below 2°C within 24 hours after placement. Slurry surfacing systems will typically resist rain induced damage after as little as one hour but typically require at least three hours to cure to a fully waterproof state. Additionally, breaking time for a slurry system is affected by ambient temperature. Figure 9-14 shows the effect of temperature on the breaking rate of emulsion.

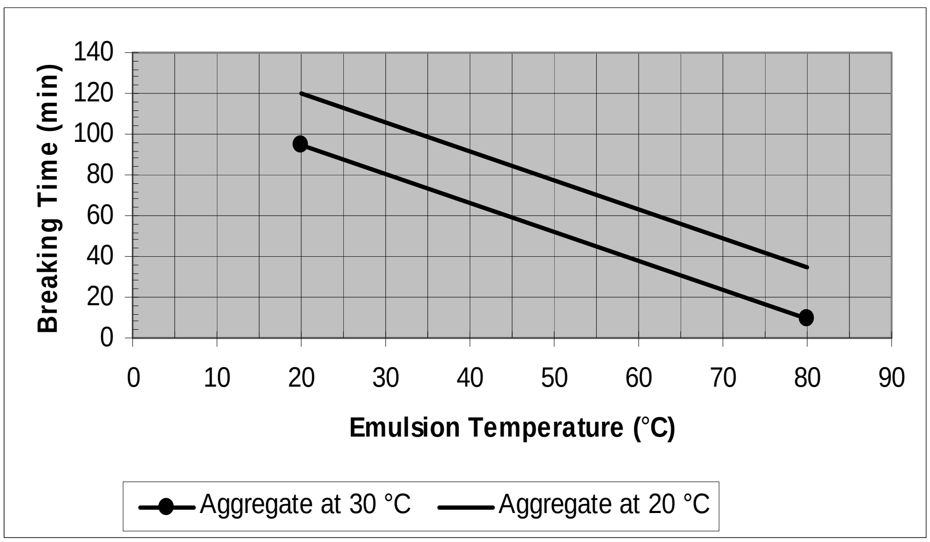


Figure 9-14 Effect of Temperature on Break Rate

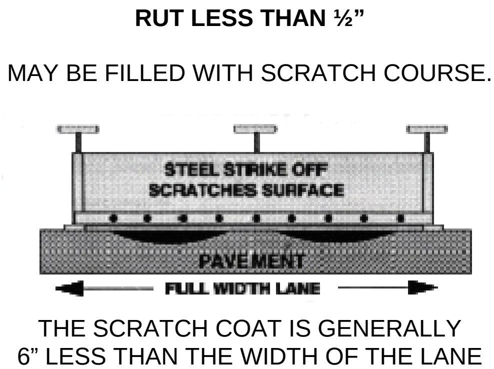
9.5.6 Types of Applications

Full Width Seal

When applying a full width seal a standard spreader box is used. Three passes are typically used for a two-lane roadway. This allows clean edges and minimizes overlaps (usually 3 in (75 mm)). Overlapped seals should only be used when the pavement being sealed is level and in sound condition.

Scratch Coat

Scratch coats are used to level pavements with minor transverse irregularities that are narrower than the width of the spreader box, or on pavements with longitudinal ruts less than 0.5 in (12.5 mm) deep. When applying a scratch coat a steel strike-off is substituted for the secondary strike-off in the standard micro-surfacing drag box. The steel strike-off drags over the high spots of the pavement, filling in the irregularities. Such materials are highly friable and stone loss is often high. Scratch coats should always be covered with a surface seal. The scratch coat principle along with a photo of a finished section is illustrated in Figure 9-15.



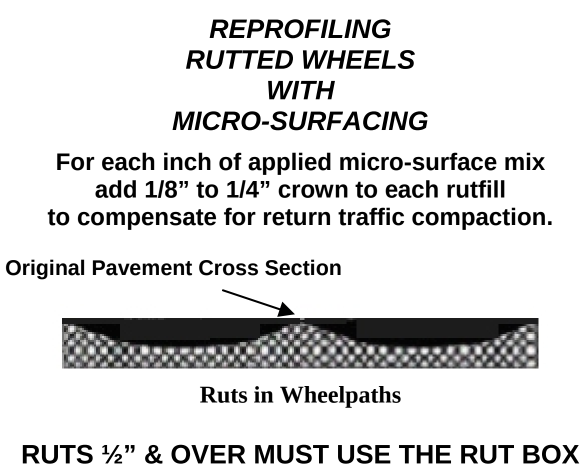
a) Scratch Coat Principle

b) Example of a Scratch Coat Treatment

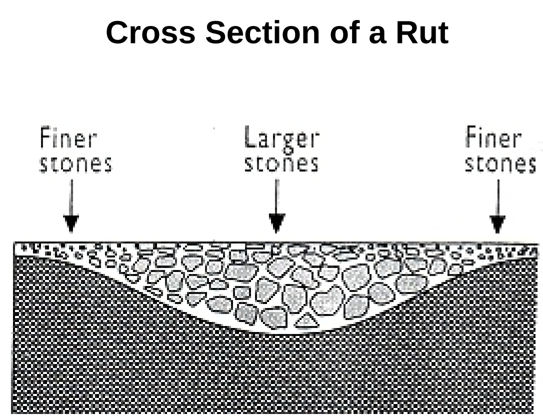
Figure 9-15 Scratch Coat Principles and Treatment

Rut Filling

Ruts may be filled with a high stability micro-surfacing mix. A rut box is essential for this application; it channels mix into the ruts and leaves a crowned finish to compensate for post compaction due to trafficking. Generally, ruts filled in this manner are covered with a surface seal, but this is not essential. Rolling is often incorporated to ensure compaction of the mix placed in rutted surfaces. Figure 9-16 illustrates the principle behind rut filling and provides a cross sectional diagram of a filled rut. Rut filling should only be used on stable ruts that have resulted from long-term traffic compaction. If rutting is ongoing, the micro-surfacing will not prevent its continued development. Figure 9-17 illustrates both suitable and unsuitable candidates for rut filling.



a) Principle of Rut Filling (Holleran, 2002)



b) Cross Section of a Filled Rut (Holleran, 2001)

Figure 9-16 Rut Filling Principle and Sectional Diagram

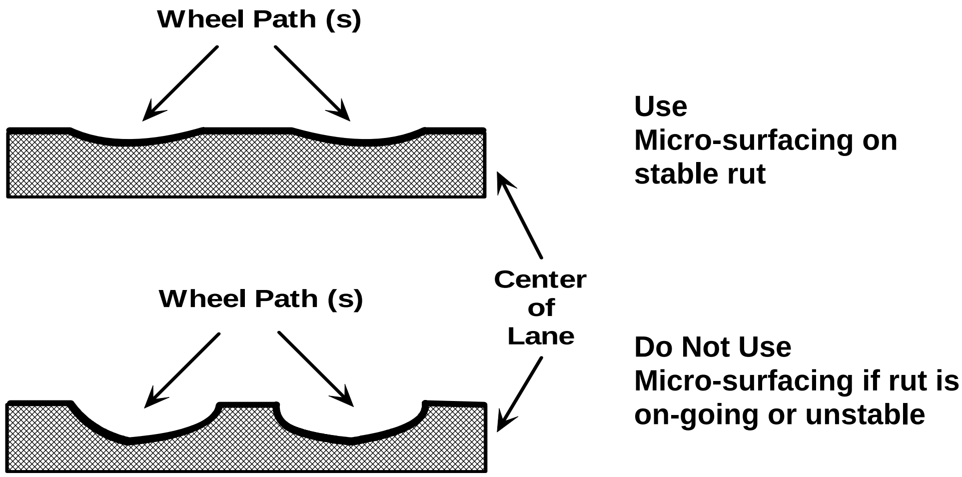


Figure 9-17 Suitable and Unsuitable Surfaces to Use Micro-surfacing as a Rut Filler

9.5.7 Quality Issues

Quality control is critical during the constriction process to achieve a uniform surface finish. The main areas of concern are discussed below.

Longitudinal Joints

Longitudinal joints may be overlapped or butt jointed. They should be straight or curve with the traffic lane. Overlaps should not be in the wheel paths and should not exceed 3 in (75 mm) in width. Figure 9-18 illustrates high quality and poor quality longitudinal joints.

a) High Quality Longitudinal Joint b) Poor Quality Longitudinal Joints

Figure 9-18 Longitudinal Joints

Transverse Joints

Transverse joints are inevitable when working with batch systems; every time a truck is emptied a transverse joint is required. Transitions at these joints must be smooth to avoid creating a bump in the surface. The joints must be butted to avoid these bumps and handwork should be kept to a minimum. The main difficulty in obtaining a smooth joint occurs as the slurry machine starts up at the joint, particularly when working with micro-surfacing that is difficult to work by hand and breaks quickly. Some contractors tend to over wet (add too much water) to the mix at start-ups. This leads to poor texture and scarring at the joints. Starting transverse joints on roofing felt can eliminate these problems. Figure 9-19 illustrates high quality and low quality transverse joints.

a) High Quality Transverse Joint

b) Low Quality Transverse Joint

Figure 9-19 Transverse Joints

Edges and Shoulders

Slurry sealed edges and shoulders can be rough and look poor. This occurs more often with micro-surfacing applications, which break quickly, making them harder to work by hand than slurry seals. For micro-surfacing, handwork should be kept to a minimum. The edge of the spreader box should be outside the line of the pavement and edge boxes should be used when shoulders are covered. Figure 9-20 illustrates high quality and poor quality edge and handwork.

a) High Quality Edges and Shoulder

b) Poor Quality Edges and Shoulder

Figure 9-20 Edges and Shoulders

Uneven Mixes and Segregation

Poorly designed slurry mixtures or mixtures with low cement content or too high a water content may separate once mixing in the box has ceased. This leads to a black and flush looking surface with poor texture. Separated mixes may lead to a "false slurry" where the emulsion breaks onto the fine material. In such instances delamination may occur, resulting in premature failure. These types of mixes can be recognized as non-uniform mixes that appear to be setting very slowly. Figure 9-21 illustrates segregation and delamination resulting from a false slurry.

a) Segregation

b) Delamination from a False Slurry

Figure 9-21 Poor Mixes

Smoothness Problems

Slurry surfacing systems follow the existing road surface profile and thus do not have the ability to significantly change the pavement's smoothness. However, when using stiffer mixes the spreader box may, if incorrectly set up, chatter or bump as the material is spread and produce a washboard effect. The chattering may be addressed by making the mixture slower to set, adjusting the rubbers on the box, or adding weight to the back of the spreader box. Figure 9-22 illustrates the washboard effect.

Figure 9-22 Wash Boarding Effect

Damage Caused by Premature Reopening to Traffic

The slurry seal or micro-surfacing must build sufficient cohesion to resist abrasion due to traffic. Early stone shedding is normal, but should not exceed 3%. If a mixture is reopened to traffic too early it will ravel off quickly, particularly in high stress areas. It is important that the mixture has formed adequate cohesion before it is opened. Choosing the right time to reopen a surface to traffic is based largely on experience. However, a general rule of thumb for a slurry seal is that it can be opened when it has turned black; a micro-surfacing can carry traffic when it is expelling clear water. Figure 9-23 illustrates raveling caused by premature opening to traffic.

Figure 9-23 Traffic Damage Caused by Early Trafficking

9.5.8 Post Construction Conditions

Emulsion systems do not lose all water in the first hours after placement; the total water loss process can take up to several weeks. During this period the surface will be water resistant; however, if the water freezes, it can cause rupture of the binder film and subsequent raveling. For this reason, projects should not be started without a 2-week window when freezing weather will not occur.

Asphalt emulsion based systems cannot re-emulsify; however, if not fully cured, these systems can be tender enough to re-disperse under the effects of traffic loading and excessive water, especially ponding water. In this process, broken aggregates or asphalt particles that have not fully coalesced into films are dispersed in water, which disintegrates the emulsion. Thus, while light rain 3 hours after placing a slurry seal is acceptable, heavy rain coupled with heavy traffic will likely lead to surface damage, especially in high shear (e.g., turning movement) areas. Figure 9-24 illustrates damage caused by heavy rain in a high shear location.

Figure 9-24 Damage Due to Post Application Heavy Rain with Shear

9.5.9 Post-Treatments

Rolling

Slurry seals will lose stone until the surface voids have been closed off, but it is acceptable for approximately 3% of surface stone to be lost. To limit the amount of loss, rolling with pneumatic rollers may be incorporated. For rut filling applications, rolling is almost always recommended. The roller should be light (6-7 tones maximum) and non-ballasted. One to two passes at a slow speed are recommended. This allows the water to be pressed to the surface, promoting evaporation and curing. Larger stones will be properly embedded, reducing early raveling. Figure 9-25 illustrates a typical roller operation.

Figure 9-25 Rolling a Slurry Surfacing

Rolling is always used on airports due to the low traffic and the seriousness of losing stone in areas where jet engines operate. Figure 9-26 illustrates the rolling of an airport taxiway.

Figure 9-26 Rolling of an Airport Taxiways

Sweeping

On heavily trafficked roads or where opening has lead to excessive stone loss, sweeping is essential. A suction broom is the best type of sweeper to use. Sweeping should be done just prior to opening to traffic and at periods determined by the level of stone loss. Figure 9-27 illustrates a suction broom.

Figure 9-27 Sweeping with a Suction Broom

Sanding

Sanding may be used to reduce the times that cross streets or intersections are closed. Sanding is the application of a fine layer of dry, washed sand that is broadcast over the slurry surface. Sanding may also be used on wet spots. Sanding should not be done until the slurry can withstand walking traffic. Figure 9-28 illustrates the use of sanding at a cross street.

Figure 9-28 Sanding at a Cross Street

9.6 TROUBLESHOOTING AND FIELD CONSIDERATIONS

9.6.1 Troubleshooting Guide

This section provides information to assist the maintenance personnel in troubleshooting problems with micro-surfacing, along with "do's and don'ts" that address common problems that may be encountered during the course of a project. The troubleshooting guide presented in Table 9-6 associates common problems to their potential causes. For example, an unstable emulsion, too little water in the mix, incompatibility between the emulsion and the aggregate, and so on, may cause a slurry surface to delaminate.

Table 9-6 Trouble Shooting Micro-surfacing Seal Job Problems

CAUSE	PROBLEM									
	BROWN	WHITISH	WON'T SET	POOR COATING	DELAYED OPENING TO TRAFFIC	BREAKS IN BOX	RAVELS	FLUSHES	DELAMINATION	SEGREGATION
EMULSION										
Emulsion Unstable				•		•			•	
Emulsion too Stable	•		•		•		•			
Emulsion too hot						•				
Too Little Emulsion	•			•			•			
Too Much Emulsion								•		
MIX										
Too many fines				•		•	•			
Too much cement		•				•				
Too little cement			•		•		•			•
Too little additive				•		•	•			
Too much additive		•	•		•		•			
Too much water	•		•		•		•	•		•
Too little water		•		•		•	•		•	
Aggregate/emulsion not compatible			•	•	•		•		•	•
CONDITIONS										
Too hot	•			•		•	•	•		
Too cold			•		•		•		•	
Rain	•		•	•	•		•	•	•	
High humidity		•	•							
SURFACE										
Fatty			•					•		

In addition to the troubleshooting guide, Table 9-7 lists some commonly encountered problems and their recommended solutions.

Table 9-7 Common Problems and Related Solutions

PROBLEM	SOLUTION
UNEVEN SURFACE – WASH BOARDING	• Ensure the spreader box is correctly set up. • Ensure the viscosity of the mix is not too high. • Make adjustments so that the mix does not break too fast. • Wait until the ambient temperature is lower. • Use water sprays on the front of the spreader.
POOR JOINTS	• Reduce the amount of water at start up. • Use water spray if runners of spreader box are running on fresh micro-surfacing.
EXCESSIVE RAVEL	• Add cement and reduce additive so that the mix breaks and cures faster. • Check aggregate to ensure the clay fines are not too high. • Control traffic longer and at low speeds. • Wait until fully cured before allowing traffic. • Wait until mix is properly set before brooming or opening to traffic.

9.6.2 Field Considerations

The following tables are guides to the important aspects of performing a micro-surfacing project. The tables list items that should be considered in order to promote a successful job outcome. The answers to these questions should be determined, as required, before, during, and after construction. The appropriate staff to do this will vary by job type and size. Some topics may need attention from several staff members. The field supervisor should be acquainted with its contents.

The intention of the table is not to form a report but to bring attention to important aspects and components of the slurry surfacing project process. Some information is product specific and contained in the relevant standard specifications, special standard provisions, or special provisions.

PRELIMINARY RESPONSIBILITIES	
PROJECT REVIEW	• Is the project a good candidate for micro-surfacing? • Should a micro-surfacing seal be used? • What is the depth and extent of any rutting? • How much and what type of cracking exists? • Is crack sealing needed? • How much bleeding or flushing exists? • Is the pavement raveling? • What is the traffic level? • Is the base sound and well drained? • Have the project bid/plan quantities been reviewed?
DOCUMENT REVIEW	• Bid specifications • Mix design information • Special provisions • Construction manual • Traffic control plan (TCP) • Material safety data sheet
MATERIALS CHECKS	• Has a full mix design and compatibility test been completed? • Is the binder from an approved source (if required)? • Has the binder been sampled and submitted for testing? • Does the aggregate meet all specifications? • Is the aggregate clean and free of deleterious materials? • Is the aggregate dry? • Is the emulsion temperature within application temperature specifications?

PRE-SEAL INSPECTION RESPONSIBILITIES	
SURFACE PREPARATION	• Is the surface clean and dry? • Have all pavement distresses been repaired? • Has the existing surface has been inspected for drainage problems?
EQUIPMENT INSPECTION CONSIDERATIONS	
BROOM	• Are the bristles the proper length? • Can the broom be adjusted vertically to avoid excess pressure?
CALIBRATION OF EQUIPMENT	• Has each machine been calibrated with the project's aggregate and emulsion? • Who carried out calibration and what documentation has been provided?
MICRO-SURFACING MACHINE	• Is the machine fully functional? • Has the machine been calibrated for this project's aggregate and certified. Is the spreader rubber clean and not worn? • Is the texture rubber clean and set at the right angle? • Are all paddles in the pug mill are intact? • Is the spreader box clean and is it a micro-surfacing type box?
ROLLERS (IF USED)	• Do the roller tire pressures comply with the manufacturer's specification? • What type roller will be used on the project (pneumatic-tired roller recommended)? • Do the roller tire size, rating, and pressures comply with manufacturer's recommendations? • Is the pressure in all tires the same? • Do all tires have a smooth surface?
STOCKPILE	• Is the stockpile site well drained and clean? • Does the Contractor have all of the equipment required at the stockpile site (loaders, tankers, and so on)?

EQUIPMENT INSPECTION CONSIDERATIONS	
EQUIPMENT FOR CONTINUOUS RUN OPERATIONS	• Is all equipment free of leaks? • Are "Flow boys" or other nurse units clean and functional? • Are there enough units to allow continuous running with minimal stops for cleaning box rubbers?
SITE CONSIDERATIONS	
WEATHER REQUIREMENTS	• Have air and surface temperatures been checked at the coolest location on the project? • Do air and surface temperatures meet agency requirements? • Are adverse weather conditions expected? High temperatures, humidity, and wind will affect how long the emulsion takes to break. • The application of the slurry surfacing does not begin if rain is likely? • Are freezing temperatures expected within 24 hours of the completion of any application runs?
TRAFFIC CONTROL	• Do the signs and devices used match the traffic control plan? • Does the work zone comply with Caltrans requirements? • Flaggers do not hold the traffic for extended periods of time? • Unsafe conditions, if any, are reported to a supervisor (contractor or agency)? • The pilot car leads traffic slowly, 24 mph (40 km/h) or less, over fresh micro-surfacing? • Signs are removed or covered when they no longer apply?
APPLICATION CONSIDERATIONS	
DETERMINING APPLICATION RATES	• Have agency guidelines and requirements been followed? • Have rut filling and leveling course application rates been calculated or estimated separately? • Has a full mix design been done? • Is more material applied to dried-out and porous surfaces? • Is more material applied on roads with low traffic volumes? • Is less material applied to smooth, non-porous, and asphalt-rich surfaces? • Has moisture content been adjusted in the application rate?

PROJECT INSPECTION RESPONSIBILITIES	
MICRO-SURFACING APPLICATION	• Has a test strip been done and is it satisfactory? • Have field tests been carried out and are the results within specification? • Are enough trucks on hand to keep a steady supply of material for the slurry machine? • Does the application start and stop with neat, straight edges? Will an edge box be used? • Is a rut box is used for ruts deeper than ½” (12 mm)? • Is a leveling course used with a steel strike-off for ruts less than ½” (12 mm)? Two courses are used where rut filling or leveling is employed. • Does the application start and stop on building paper or roofing felt? • Are drag marks present due to oversize aggregate or dirty rubbers? • Are rubbers cleaned regularly and at the end of each day? • Does the machine take a straight, even line with minimal numbers of passes to cover the pavement? • Is the mix even and consistent? • Are fines migrating to the surface? • Is the application stopped as soon as any problems are detected? • Does the application appear uniform? • Does the surface have an even and uniform texture? • Is the application rate checked based on amounts of aggregate and emulsion used? • What is the time between spreading, foot traffic, and opening to vehicular traffic?
ROLLING	• Does rolling wait until the mat is stable? Roller is 5-6 tones (7) maximum. • Is the entire surface rolled only once? • Do the rollers travel slowly, 5 mph (8-9 km/h) maximum?
TRUCK OPERATION	• Are trucks staggered across the fresh seal coat to avoid driving over the same area? • Do trucks travel slowly on the fresh seal? • Are stops and turns made gradually? • Do truck operators avoid driving over the micro-surfacing? • Do truck operators stagger their wheel paths when backing into the paving unit?
LONGITUDINAL JOINTS	• Is the meet line overlapped a maximum of 3 in (75 mm)? • Do the spreader box runners avoid running on fresh mat? • Are the meet lines made at the center of the road, center of a lane, or edge of a lane not in the wheel paths?

PROJECT INSPECTION RESPONSIBILITIES	
TRANSVERSE JOINTS	• Do all applications begin and end on building paper? • Mixture is not too wet at start up? • Is the building paper disposed of properly?
BROOMING	• Does brooming begin after the micro-surfacing can carry traffic? • Does brooming dislodge the micro-surfacing? • Is the surface raveling? Follow-up brooming should be done if raveling is high or if traffic is high.
OPENING THE MICRO-SURFACING TO TRAFFIC	• Does the traffic travel slowly - 24 mph (40 kph) or less over the fresh micro-surfacing? • Are reduced speed limit signs used when pilot cars are not used? • After brooming, have pavement markings been placed before opening to traffic? • Have all construction-related signs been removed when opening to normal traffic?
CLEAN UP	• Have all loose aggregate from brooming been removed from traveled way prior to opening to traffic? • Have all binder spills been cleaned up?

9.7 REFERENCES

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CHAPTER 10 THIN MAINTENANCE OVERLAYS

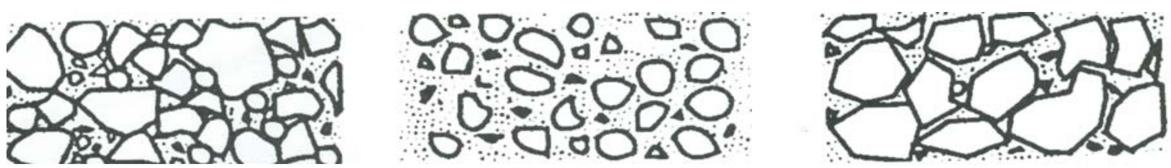
10.1 OVERVIEW

For the purposes of this advisory, maintenance overlays are defined as thin treatments using a hot mix system as defined in the Standard Specifications or Standard Special Provisions of the California Department of Transportation (Caltrans, 2007). A thin treatment for the purposes of this chapter is a non-structural layer and is applied as a maintenance treatment, either corrective or preventive. Nationally, thin treatments are less than 1½ inches (37.5 mm) in thickness. In Caltrans, thin blankets are 1.2 inch (30 mm) thick.

Historically, three maintenance overlay types have been used by Caltrans, either alone or in combination with other treatments such as Stress Absorbing Membrane Inter-layer (SAMI). They include:

- Dense Graded Thin Blankets (HMA-A and HMA-B)
- Open Graded (OGFC, RHMA-O, and RHMA-O-HB)
- Gap Graded Mixes (RHMA-G)

The different mixes are defined based on their aggregate grading, binder content, and voids content. Figure 10-1 illustrates, in general, the differences in aggregate structure for these mix types.



a) Dense Graded b) Gap Graded c) Open Graded

Figure 10-1 Stone Matrices Created by Different Gradings (Austroads, 2000)

This chapter describes each of these mix types in further detail and provides an overview of the design and construction of these mixtures.

10.2 DENSE-GRADED OVERLAYS

10.2.1 Dense-Graded Mixes

Dense graded mixtures have an aggregate structure that is continuously graded (sized) from the largest to the smallest aggregate in the system. They are mixed in a continuous drum type hot mix plant or a batch plant. An appropriate asphalt grade should be selected based on the climatic region and anticipated distress mode. Asphalts could be modified to adjust properties for these conditions. For example, modified asphalts may be used if it is anticipated that thermal cracking may occur due to a single severe temperature drop (Asphalt Institute, 1998) and/or during cooler (night) paving conditions. Now PG asphalts are used with these mixes and the graded is selected based on the climatic region and anticipated distress conditions. Asphalt rubber (wet process) is not usually used in dense graded mixtures due to the more difficult compaction characteristics associated with thin layers and less resistance to reflective cracking.

The aggregate gradations for dense graded mixes are provided in the Standard Specifications (Caltrans, 2007). It should be noted that for thin overlays of 1 to $1^{1}/_{2}$ in (25 to 37 mm) the stone size was previously limited to a maximum of one-half the thickness of the layer, but this was changed to one-third in the new section 39 specifications. Table 10-1 shows the required aggregate physical requirements as specified in the Standard Specifications.

Table 10-1 Aggregate Quality Requirements (Caltrans, 2007)

Quality Characteristic	Test Method	HMA Type			
		A	B	RHMA-G	OGFC
Percent of crushed particles	CT 205				
Coarse aggregate (% min.)					
One fractured face		90	25	--	90
Two fractured faces		75	--	90	75
Fine aggregate (% min)					
(Passing No. 4 sieve and retained on No. 8 sieve.)		70	20	70	90
Los Angeles Rattler (% Max.)	CT 211				
Loss at 100 Rev.		12	--	12	12
Loss at 500 Rev.		45	50	40	40
Sand equivalent [a] (min.)	CT 217	47	42	47	--
Fine aggregate angularity (% min.) [b]	AASHTO T 304 Method A	45	45	45	--
Flat and elongated particles (% max. @ 5:1)	ASTM D 4791	10	10	10	10
K_c factor (max.)	CT 303	1.7	1.7	1.7	--
K_f factor (max.)	CT 303	1.7	1.7	1.7	--

Notes:

a Reported value must be the average of 3 tests from a single sample.

b. The Engineer waives this specification if HMA contains less than 10 percent of nonmanufactured sand by weight of total aggregate.

10.2.2 Dense-Graded Overlays Performance

Dense graded mixtures have relatively low air void contents and are designed as an abrasion resistant and functionally impermeable wearing course. Historically, dense graded mixtures have been the most commonly used mix type for overlaying asphalt or portland cement concrete pavements. The following paragraphs provide a brief overview of the distresses that occur in dense graded thin overlays as well as the factors influencing job selection, service lives, and costs.

Distresses Addressed

Conventional dense graded thin overlays should only be placed on structurally sound pavements. That is because they offer little structural improvement, but they can renew the surface in terms of functional performance (i.e., ride quality). They can be used to mitigate the following distresses present in an existing pavement:

- Raveling
- Oxidation
- Minor Cracking
- Minor Surface Irregularities
- Skid Problems
- Pavement Water Proofing (requires correct tack coating practices)

When used in association with a SAMI, or fabric interlayer, they may also address reflective cracking. In addition, modified asphalt binders can be used to address low temperature cracking and reflective cracking.

Primary Distress Modes

Dense graded thin overlays exhibit the following distress modes:

- Permanent deformation due to heavy traffic and high temperatures.
- Fatigue cracking due to repeated traffic loading.
- Reflection cracking due to cracks in the existing pavement reflecting up through the overlay.
- Raveling due to a number of factors including oxidation and hardening of the binder, water damage, low binder content, and low compaction.
- Stripping (water damage).
- Delamination due to poor compaction and/or tack coat practices.

Often, these can be addressed by selection of the correct binder and proper mix design. The principal failure modes of dense graded thin overlays are delamination, raveling and cracking due to poor compaction. Thin layers cool faster than thick layers reducing the time available for proper compaction. Thus, if a thin overlay is not compacted properly, it will tend to be less cohesive and ravel or delaminate.

Job Selection

Thin blanket overlays should only be used on sound pavements where minor defects are present and all construction requirements can be met, especially compaction. Variables that affect job selection include:

- **Traffic Loading:** In low volume roads, variations in traffic need to be taken into account. Selection should be based on the worst-case scenario. For high volume roads, the principal failure modes are fatigue cracking and permanent deformation. To resist fatigue cracking a thin blanket can be used to extend the pavement life for 1-3 years depending on the mix type.

- **Existing Pavement Condition:** Dense graded thin overlays should only be used on pavements that do not possess a significant amount of distress. For example, existing pavements with significant quantities of medium to high severity fatigue cracking are poor candidates for a thin overlay. Conversely, pavements that possess distresses that affect the functional performance of the existing pavement (e.g., rideability, poor skid resistance, oxidation, etc.) are generally good candidates for thin overlays provided that a structural enhancement of the existing pavement is not required. Sometimes a thin overlay (with a SAMI) is placed over poor roads to prolong the period until rehabilitation.

- **Environment:** With proper mix design (i.e., appropriate binder type and content for a given aggregate type and gradation) these mixes have been successfully used in a range of climates. In all climates fatigue cracking can be the principle mode of failure. In hot climates permanent deformation (rutting) can be the principle mode of failure whereas in climates where large temperature swings occur thermal cracking can be the principal mode of failure. Use of a dense graded thin overlay must take into account the climate in which it is placed in order to avoid distresses that commonly occur in a particular climate.

However, in practice, Caltrans maintenance typically overlays medium to high fatigue cracked pavements to slow deterioration and prevent pot holes from occurring. The thin overlay is often a stop gap treatment until the proper corrective action can be taken.

Service Life and Costs

Dense graded thin overlays have been shown to last 2 to 10 years, but more commonly last between 4 and 6 years (Hicks, 2000). The life of the overlay is directly affected by the condition of the existing pavement that received the overlay, the climate (environmental conditions) in which the overlay was placed, and the traffic loading experienced by the overlay. For example, a thin overlay placed on a pavement in poor condition would not be expected to last as long as one placed on a pavement in good condition. Similarly, a thin overlay placed on a pavement in good condition but with heavy traffic would not be expected to last as long as one placed on the same pavement, but with much lighter traffic.

Numerous factors influence the cost of dense graded thin overlays. Several of the principle factors contributing to the cost of placing a dense graded thin overlay include:

- Materials (binder and aggregate with or without modifiers).
- Location of the project (e.g., urban versus rural area, proximity to hot mix plant, etc.).
- Thickness of the overlay.
- Special construction requirements (e.g., stricter control of compaction relative to conventional overlays or night work).

Chapter 3 provides a simplified framework of selecting cost effective treatments.

10.2.3 Dense-Graded Overlays Design and Specifications

The Hveem method, developed by Caltrans Translab in the 1940s, is presently used for dense graded hot mix design. The Hveem method is covered extensively through various references (Caltrans, 2007, Asphalt Institute, 1998, Army Corps of Engineers, 1991, Asphalt Institute, 1988) and the test methods may be found on http://www.dot.ca.gov/hq/esc/ctms/indexhtml .

The Hveem method uses a series of test methods to determine optimum binder content. These test procedures include use of a centrifuge to measure surface porosity and particle roughness (CT303). CT206 and 208 are used to measure the specific gravity of the fine and coarse aggregate respectively. Knowing the specific gravity of the fine and coarse aggregate and conducting CT 303 leads to the determination of an approximate bitumen ratio. A series of test specimens is prepared at a range of asphalt contents above and below the approximate bitumen ratio (i.e., approximate binder content). This preparation method uses a kneading compaction device. A stability test to evaluate the resistance to deformation (CT366) is performed, as well as a swell test to determine the effect of water on volume change and permeability of the specimen (CT305). Finally the specimens are tested for moisture vapor susceptibility (CT307) to determine the extent to which the stability values are affected by moisture vapor. Table 10-2 shows the required properties of the mixture as specified in the Standard Specifications (Caltrans, 2007).

Table 10-2 Hot Mix Asphalt for Job Mix Formula (Caltrans, 2007)

Quality Characteristic	Test Method	HMA Type		
		A	B	RHMA-G
Air voids content (%)	CT 367[a]	4.0	4.0	Special Provisions
Voids in mineral aggregate (% min.)	LP-2			
No. 4 grading		17	17	--
3/8" grading		15	15	--
1/2" grading		14	14	18 – 23[b]
3/4" grading		13	13	18 – 23[b]
Voids filled with asphalt (%)	LP-3	65 - 75	65 - 75	Note d
Dust proportion	LP-4			
No. 4 and 3/8" gradings		0.9 – 2.0	0.9 – 2.0	Note d
1/2" and 3/4" gradings		0.6 – 1.3	0.6 – 1.3	
Stabilometer value [c](min.)	CT 366			
No. 4 and 3/8" gradings		30	30	--
1/2" and 3/4" gradings		37	35	23

Notes:

a. Calculate the air voids content of each specimen using California Test 309 and Lab Procedure LP-1. Modify California Test 367, Paragraph C5, to use the exact air voids content specified in the selection of OBC.
b. Voids in mineral aggregate for RHMA-G must be within this range.
c. Modify California Test 304, Part 2.B.2.c: "After compaction in the compactor, cool to 140 degrees ± 5 degrees F by allowing the briquettes to cool at room temperature for 0.5-hour, then place the briquettes in the oven at 140 degrees F for a minimum of 2 hours and not more than 3 hours."
d. Report this value in the JMF submittal.

10.2.4 Dense-Graded Overlays Material Requirements

Dense graded asphalt concrete (DGAC) must be comprised of materials capable of resisting degradation during construction as well as providing good long-term durability. Thus, the aggregates must be sufficiently hard to resist breakage during compaction and be sufficiently compatible with the binder so as to resist de-bonding of the binder in the presence of water (i.e., resist stripping). Other characteristics, such as particle shape, are also important. Similarly, the binder must be of sufficient quality to resist the effects of aging (i.e., oxidation and associated hardening). In this sense, it is desirable to have a relatively soft binder or to have a mixture with a relatively thick binder film. However, the binder must also be hard (stiff enough) and the mixtures not have too thick a binder film so as to resist permanent deformation. Thus, the binder grade (e.g., PG 64-10, PG 64-16, etc.) are often selected to resist these conflicting requirements. Modified binders can be incorporated into the mixture to assist in optimizing resistance to a particular distress mode.

Chapter 2 has more information on materials requirements. Information on the use of rubber-modified mixtures can be found in the Caltrans Asphalt Rubber Usage Guide (Caltrans, 2006).

10.2.5 Dense-Graded Asphalt Concrete (DGAC) Overlay Construction

Safety

Standard Caltrans safety and traffic control procedures must be followed. These procedures are detailed in Caltrans references (1999 and 2003).

Manufacture

Aggregates and binder are mixed using either a batch plant or drum mixing plant (Caltrans, 2007). References including the Asphalt Institute (1998) and Army Corps of Engineers (1991) have extensive sections on plant types and correct operation. Important factors prior to mixing are appropriate storage of binder and aggregates and adequate drying of aggregates. Correct proportioning of aggregates and binder is important as is correct mixing temperatures (see Chapter 2) to allow full coating of the aggregates during the actual mixing process.

Storage

Currently DGAC should not be stored in silos for periods greater than 18 hours. Material with hardened lumps cannot be used. The Standard Specifications (Caltrans, 2007) details storage silo requirements as does References Asphalt Institute, 1998 and Army Corps of Engineers, 1991.

Hauling

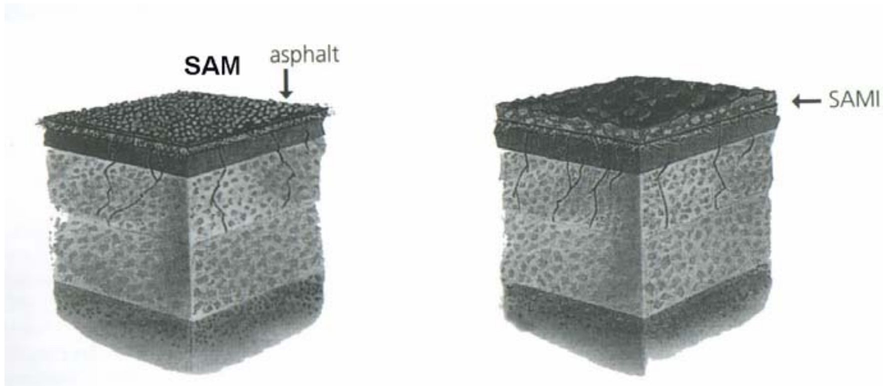
Standard hauling equipment (i.e., end dump vehicles, bottom dump vehicles, or live bottom dump vehicles) may be used for the construction of dense graded thin overlays. U.S. Army Corps of Engineering (1991) contains further information regarding these types of vehicles. Tarping is advised to prevent any crusting of the mixture (i.e., hardening of the first few centimeters of the mixture exposed to ambient temperatures), especially in night and cool weather work with modified mixes, or when long haul distances are required. Release agent should be used on the truck tray. On no account should diesel or other petroleum materials be used as release agents as these will soften the mixture.

Care must be taken in handling the mixture to ensure segregation does not occur. This may happen if the mix is not correctly loaded at the plant, is poorly designed, or not handled correctly. For larger jobs, a re-mixer “shuttle buggy” might be considered.

Surface Preparation

Surface preparation is critical for good performance of any overlay. Thin maintenance overlays should only be placed on sound pavements. This means that pavement failures must be repaired first. Cracks should be sealed and any potholes patched. Crack sealing and patching practices were covered in Chapters 4 and 5, respectively.

In some cases a SAM or SAMI (Figure 10-2) may be used over pavements with low severity fatigue cracking in small quantities (e.g., isolated areas). The overlay may be applied a year or more after a SAM seal or immediately following application of a SAMI. Surfaces should be thoroughly swept before application of the overlay to remove debris that could prevent a good bond between the existing pavement and the overlay. Flushing with water may be needed where the pavement is exposed to agriculture product drippings.



a) Stress Absorbing Membrane Seal b) Stress Absorbing Membrane Interlayer

Figure 10-2 SAM Seal and SAMI (Austroads, 2000)

Tack Coat

Tack coats are applications of asphalt sprayed onto an existing pavement prior to an overlay being applied. The tack coat promotes adhesion between old and new pavement layers (Asphalt Institute, 1998).

Good tack coat practice must be followed. The Standard Specifications Section 39-4.02 (Caltrans, 2007) specifies how to apply tack coats in a manner satisfactory to Caltrans. Surfaces must be clean before the tack coat is applied. If a good bond is not formed between the thin overlay and the existing pavement, it can de-bond resulting in a slippage failure or delamination. If too much tack coat is applied, it may bleed up through the layer, especially under heavy traffic.

Tack coat should be applied via a calibrated distributor with nozzles set at an angle of about 30 degrees to the spray bar. The height should allow a triple overlap (see Chapter 5). A tack coat should be applied in one application at the residual rate determined by the Section 39-1.09C (Caltrans, 2007).

Laydown

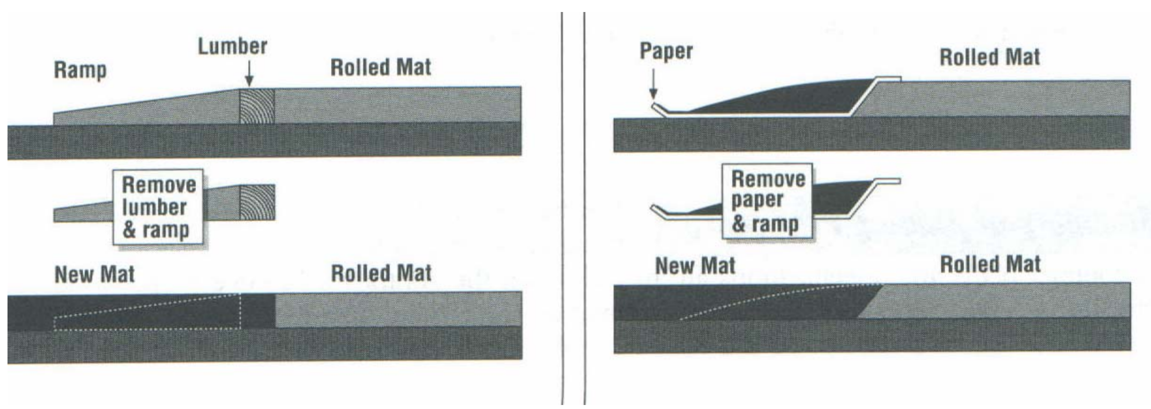
Dense graded mixes may be windrowed ahead of the paver and picked up with a pick up device (loader) and deposited in the paver hopper. The length of the windrow must be as short as possible to ensure excessive cooling does not occur. If conditions are good (i.e., little or no wind and higher temperatures), this is usually about 160 ft (50 m) maximum (Hicks, 2000). If conditions are poorer than this, the length of the windrow should be kept less than 160 ft (50 m). Table 10-3 summarizes minimum application temperatures for the various stages of the construction process. Every effort should be made to avoid segregation of the mixture during the paving operation. In addition, mix that is left in the paver hopper too long and, thus, allowed to cool below the minimum laydown temperature should not be combined with fresh mix.

Table 10-3 Recommended Application Temperatures (Caltrans, 2007)

BINDER TYPE	**MINIMUM AIR TEMPERATURE, ºF**	**MINIMUM SURFACE TEMPERATURE, ºF**	**MINIMUM BREAKDOWN ROLLING TEMPERATURE, ºF**	**MINIMUM FINISHING TEMPERATURE, ºF**
CONVENTIONAL (UNMODIFIED)	55	60	250	150
PG-PM	50	55	240	140

**These are minimum temperatures. It is recommended that spreading and compacting be performed at temperatures above these minimums, but not to exceed 325ºF.*

When paving operations are to be discontinued for an extended period (e.g., end of day), it is necessary to construct a transverse joint across the pavement being placed. This can be accomplished in a number of ways and the type of joint constructed depends primarily on whether or not traffic will be allowed to travel over the joint between the time the joint is constructed and paving operations resume. If traffic won't be allowed to travel over the joint, it is recommended that a butt joint be constructed as illustrated in Figure 10-3a. Conversely, if traffic is allowed to travel over the joint, it will be necessary to construct a tapered joint as illustrated in Figure 10-3b. References Asphalt Institute (1998) and U.S. Army Corps of Engineering (1991) provide detailed guidance for constructing transverse joints.



a) Butt Joint b) Tapered Joint

Figure 10-3 Transverse Joint Formation (Asphalt Institute, 1998)

Longitudinal joints occur between adjacent travel lanes or between travel lanes and a paved shoulder. During the paving operation of a lane of pavement, the material along the edge of the pavement (i.e., where the longitudinal joint will exist) normally has about a 60-degree incline relative to the surface of the existing pavement. Prior to placement of the adjacent lane of pavement (or shoulder), this material can be either cut back (using a saw or cutting wheel attached to a grader or front-end loader) by about 2 in (50 mm) to create a vertical face, or an overlapping joint can be constructed.

Whenever a joint is created by "cutting back the joint," a tack coat should be applied to the newly exposed face of the longitudinal joint. Cutting back the joint helps to ensure that adequate density of the mixture exists at the longitudinal joint.

Properly overlapping, raking, and compacting the longitudinal joint can typically also result in adequate joint density. Figure 10-4 illustrates a technique of rolling from cold side. In this method, rolling in the first pass was done in the static mode with a major portion of the roller wheel on the cold side with about 6 inches (152 mm) of the roller wheel on the hot side of the joint. This technique is believed to produce a "pinching" effect on the joint. The second backward pass was made in the vibratory mode with roller on the hot side with about 6 inch overlap on the cold side. However, timing in this type of rolling is critical. When the roller is operated on the cold side, the hot side undergoes cooling which can make it difficult to achieve the desired compaction level (Kandahl, et al, 2002).

If the mix along the joint is clean, a tack coat is not normally needed prior to placement of the adjacent lane of pavement. Static or vibratory rollers with low amplitude setting should be used.

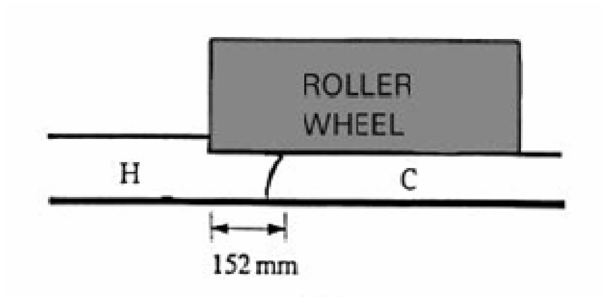
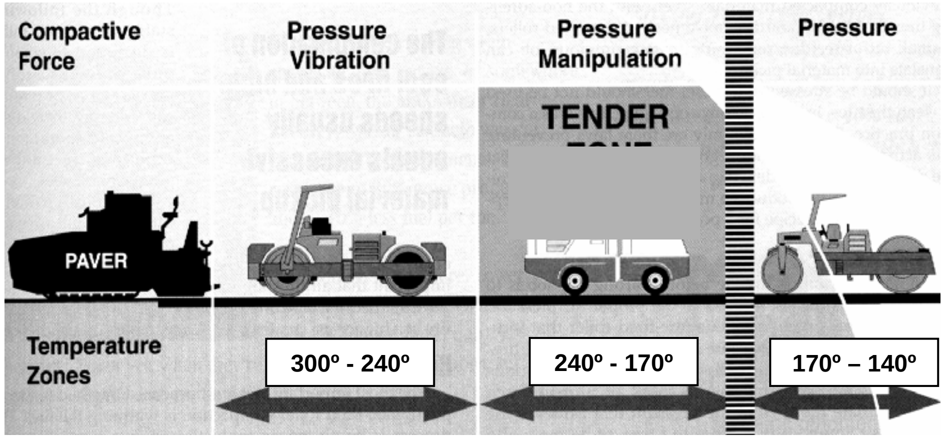


Figure 10-4 Formation of Longitudinal Joints

Rolling

There are several stages of rolling used for dense graded mixtures. Because thin layers lose temperature rapidly, the rolling temperatures must be strictly monitored. The stages for compaction include initial breakdown using a vibratory roller, kneading compaction using a pneumatic roller, and finishing using a static roller as illustrated in Figure 10-5 (Lender, 2001). The actual temperatures would vary some based on binder type.



(Temperatures given in °F)

Figure 10-5 Rolling Regimes

Acceptance

Dense graded asphalt pavements are usually accepted based on aggregate grading, binder content, and density of the in-place mixture. Acceptance criteria for method specifications are presented in Table 10-4.

Table 10-4 Acceptance – Method (Caltrans, 2007)

Quality Characteristic	Test Method	HMA Type			
		A	B	RHMA-G	OGFC
Aggregate gradation [a]	CT 202	JMF ± Tolerance [b]	JMF ± Tolerance [b]	JMF ± Tolerance [b]	JMF ± Tolerance [b]
Sand equivalent (min.) [c]	CT 217	47	42	47	--
Asphalt binder content	CT 379 or 382	JMF ± 0.45%	JMF ± 0.45%	JMF ± 0.5%	JMF +0.50 -0.70
HMA moisture content (max.)	CT 370	1.0%	1.0%	1.0%	1.0%
Stabilometer value[c, d, e] (min.)	CT 366				
No. 4 and 3/8" gradings		30	30	--	--
1/2" and 3/4" gradings		37	35	23	--
Percent of crushed particles	CT 205				
Coarse aggregate (% min.)					
One fractured face		90	25	--	90
Two fractured faces		75	--	90	75
Fine aggregate (% min)					
(Passing No. 4 sieve and retained on No. 8 sieve.)		70	20	70	90
Los Angeles Rattler (% max.)	CT 211				
Loss at 100 rev.		12	--	12	12
Loss at 500 rev.		45	50	40	40

a. The Engineer determines combined aggregate gradations containing RAP under Laboratory Procedure LP-9.

b. The tolerances must comply with the allowable tolerances in Section 39-1.02E, "Aggregate."

c. The Engineer reports the average of 3 tests from a single split sample.

d. The Engineer prepares and tests a set of 3 briquettes for each stability determination. If the stability range is more than 12 points, the Engineer prepares and tests new briquettes.

e. Modify California Test 304, Part 2.B.2.c: "After compaction in the mechanical compactor, cool to 60 degrees C ±3 degrees C by allowing the briquettes to cool at room temperature for 0.5 hour, then place the briquettes in the oven at 60 degrees C for a minimum of 2 hours and not more than 3 hours."

Caltrans Standard Specifications does specify density on pavement lifts less than 1 ½". Compaction on thin lift overlays are based on the method specification 39-3.03.

Post Treatments

Dense graded materials usually require no post-laydown treatments.

10.3 OPEN-GRADED OVERLAYS

10.3.1 Open-Graded Mixes

Open Graded Friction Course (OGFC), also referred to as Open Graded Asphalt Concrete (OGFC), is a surface course with an aggregate gradation that provides an open void structure as compared with conventional dense graded asphalt concrete (Hicks, 2000, AEMA, 1998). Air void content typically ranges between 15 to 25% in OGFC mixtures (Hicks, 2000, Kandahl, 1998, Mallick, 2000) resulting in a highly permeable mixture relative to HMA (which normally is relatively impermeable). The porous nature of OGFC mixtures allows surface water to quickly drain away from the surface by allowing the water to flow through the mixture. The principal benefit derived from OGFC mixtures is a significant reduction in splash and spray relative to HMA mixtures and PCC pavements. Other benefits include a reduction in tire noise and an increase in the frictional characteristics relative to HMA mixtures. The addition of modifiers such as polymers and asphalt rubber can be used to address different environmental and climatic conditions, and allow for thicker films to improve durability.

The aggregate gradations for open graded mixes are given in the Caltrans Standard Specifications. Table 10-5 shows the required characteristics of such aggregates as specified in the Standard Specifications. The mixture requirements are based on a drain down test and are discussed in Section 10.3.4.

Table 10-5 Aggregate Quality Requirements (Caltrans, 2007)

Quality Characteristic	Test Method	HMA Type OGFC
Percent of crushed particles	CT 205	
Coarse aggregate (% min.)		
One fractured face		90
Two fractured faces		75
Fine aggregate (% min)		
(Passing No. 4 sieve and retained on No. 8 sieve.)		90
Los Angeles Rattler (% Max.)	CT 211	
Loss at 100 Rev.		12
Loss at 500 Rev.		40
Sand equivalent [a] (min.)	CT 217	--
Fine aggregate angularity (% min.) [b]	AASHTO T 304 Method A	--
Flat and elongated particles (% max. @ 5:1)	ASTM D 4791	10
K_c factor (max.)	CT 303	--
K_f factor (max.)	CT 303	--

Notes:

a Reported value must be the average of 3 tests from a single sample.

b. The Engineer waives this specification if HMA contains less than 10 percent of nonmanufactured sand by weight of total aggregate.

10.3.2 Open-Graded Overlays Performance

OGFC is designed as an abrasion resistant wearing course that can quickly drain water from the road surface. The following paragraphs provide a brief overview of the distresses that occur in open graded thin overlays as well as the factors influencing job selection, service lives, and costs.

Distresses/Conditions Addressed

Conventional open graded thin overlays should only be placed on structurally sound pavements, but they can renew the surface in terms of functional performance (i.e., ride quality). They can be used to mitigate the following distresses present in an existing pavement (Kandahl, 1998, Mallick, 2000):

- Skid Problems/ Hydroplaning
- Splash and Spray
- Noise Problems
- Raveling
- Oxidation
- Minor Surface Irregularities (ride quality)
- Surface Reflection Problems
- Bleeding Surfaces

When used in association with a SAMI, OGFC mixes may also enhance resistance to reflective cracking. In addition, modified systems such as asphalt rubber and PG-PM binders can be used to address low temperature cracking and reflective cracking. Also, because durability is a function of film thickness (Shell, 1999), the use of modifiers (e.g. asphalt rubber) that increase in-service viscosity allow thicker films resulting in higher resistance to oxidation and raveling (Kandahl, 1998, Mallick, 2000). The void structure also allows absorption of free surface asphalt to mitigate bleeding pavements.

Principal Distress Modes

OGFC overlays exhibit the following distress modes (Hicks, 2000, Austroads, 2000, Kandahl, 1998):

- Permanent deformation due to heavy traffic loading in conjunction with high temperatures.
- Shear failures in high stress areas.
- Fatigue cracking due to repeated traffic loading.
- Reflection cracking due to cracks in the existing pavement reflecting up through the overlay.
- Raveling due to a number of factors including oxidation and hardening of the binder, water damage, low binder content, and low compaction.
- Stripping caused by binder-aggregate incompatibility.
- Delamination due to poor compaction and/or tack coat practices.
- Clogging of air voids causing loss of permeability.
- Rich and dry spots due to drain down of binder during transport and application.
- Isolated areas of softened binder due to fuel/oil spills.

Often, these can be addressed by selection of the correct binder and proper mix design and job selection. The performance of OGFC thin overlays is based on maintaining the void structure.

10.3.3 Open-Graded Overlays Job Selection

Where Should OGFC be Used?

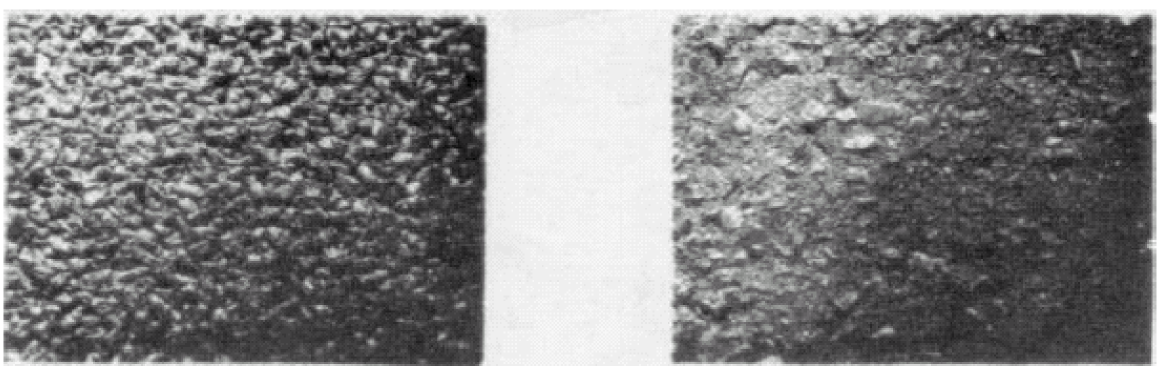
- In California, OGFC is generally used in new construction, major rehabilitation projects, and also in maintenance overlays. OGFC is used as a wearing course (i.e., surface treatment over HMA pavements and occasionally on portland cement concrete (PCC) pavements). OGFC is generally used on the traveled way and extending 1 ft (0.3 m) on the shoulder (AEMA, 1998). In maintenance applications, the distress mode of the existing pavement must be determined and addressed.
- Open graded overlays should be placed on structurally sound pavements.
- RHMA-O or RHMA-O-HB can be used to address the possibility of reflective cracking due to the existing pavement surface.

When Should OGFC be Used?

Consider using OGFC as a surface treatment when the following conditions exist:

- **Wet Weather Accidents:** Consider the use of OGFC when the Traffic Accident Surveillance and Analysis System (TASAS) Report reveals a high frequency of wet weather accidents or when the Traffic Safety Report recommends the use of OGFC to minimize wet weather accident occurrences.

- **Skid Resistance:** When frictional properties of the pavement surface are suspect, a friction test should be conducted to determine the existing coefficient of friction of the pavement surface (CT 342). Figure 9-6 shows typical surface textures of OGFC compared with HMA.



Typical Open Graded Typical Dense Graded

Figure 10-6 Typical Texture

- **Wet-night Visibility:** Another consideration for the use of OGFC is when the TASAS Report reveals a high percentile confidence level for wet weather and nighttime accident occurrences. OGFC may also be considered for placement to reduce splash and spray due to rain and increase the visibility of pavement delineation. It can be placed on both asphalt and portland cement concrete pavements.

- **Cross Slope:** When the cross slope is less than 2% and there are two or more lanes in one direction, OGFC may be especially helpful to assist in the draining of water from the pavement surface.

- **Noise:** OGFC has also been reported to reduce road noise (Kandahl, 1998, Mallick, 2000, Caltrans, 2001, FHWA, 1995, FHWA, 1990). Caltrans continues to research traffic noise on various roadway surfaces. Caltrans has reported in a study on I-80 that traffic noise levels have decreased and continue to be lower than baseline conditions 35-months after the application of OGFC (Caltrans, 2001). The life expectancy of the noise benefit varies with the mix and binder type.

- **Structural Adequacy:** Most districts do not consider OGFC to be a structural layer, rather it is considered a sacrificial layer only.

- **Oxidation Reduction:** OGFC has been successfully used as a protection layer to prevent asphalt aging in the main structural layers.

- **Mitigation against Flushing and Bleeding:** OGFC when applied to a pavement provides void structure to accommodate any potential flushing or bleeding in the underlying pavement.

- **Mitigation of Cracking:** RHMA-O-HB can be used to mitigate cracking.

Where and When Should OGFC Not be Used?

OGFC should not be used on:

- **Unstable Pavements:** OGFC should not be used on any pavement that exhibits substantial cracking, rutting, bleeding, or depressions. The extent of pavement distress precluding the use of OGFC has not been quantified at this time by Caltrans.

- **Snow or Icy Areas:** In snow areas, where tire chains, studded tires, or snowplows will detrimentally affect the aggregate and binder, the result may lead to stripping of the aggregate and contribute to raveling and pavement deterioration.

- **Areas with Severe Turning Movements:** High shear areas are not recommended for placement of conventional OGFC due to potential for scuffing. These areas may include parking areas, intersections, ramp terminals, or curbed sections. However, OGFC with modified binders has been successfully utilized in these areas.

- **Curb and Gutter/Dense Graded:** OGFC should not be placed adjacent to curb and gutter or HMA where water may be held back and stored, thus, creating a ‘bath’ that may cause striping or saturation of the structural section.

- **Muddy Areas:** Areas where mud may be tracked onto the pavement from un-surfaced side roads will fill the voids and reduce the surface water drainage characteristics of the OGFC.

- **Fuel or Oil Spill Areas:** OGFC should not be placed in areas where dripping of oil or fuel from slow or stopped vehicles is prevalent.

- **Mill and Fill Areas:** Mill and fill areas should not generally be candidates for OGFC as a bathtub effect may be created. If OGFC were to be used as the final course, a leveling course would be required first.

Special Maintenance Requirements of OGFC

Permeability must be maintained to ensure water flow is unimpeded**.** Maintenance on roadways surfaced with OGFC should avoid any activities that may obstruct the lateral flow of water through the OGFC. These activities may include crack sealing or patching a small failed area with HMA thus creating a 'dam' where water may be retained or stored and contribute to further failure of the OGFC surfacing. When large areas of patching are involved, OGFC should be replaced with OGFC. Traffic striping may also inhibit lateral water flow if the striping materials are applied at a heavy rate or excessive amount of reflective beads are used.

Winter maintenance is not as great an issue as once thought. OGFC has different thermal and icing properties compared with HMA. Thermal conductivity is up to 70% less according to National Asphalt Pavement Association (NAPA, 2002). It will act as an insulating layer and accumulate ice and frost faster than HMA.

General maintenance of OGFC to prevent clogging is important in some areas. Water hoses, high-pressure cleaners, and specialized cleaning vehicles may be used for this purpose.

Service Life and Costs

OGFC overlays have been shown to last 2 to 10 years, but more commonly 4 to 6 years (Hicks, 2000). The life of the overlay is directly affected by the condition of the existing pavement that received the overlay, the climate (environmental conditions) in which the overlay was placed, and the traffic loading experienced by the overlay. For example, a thin overlay placed on a pavement in poor condition would not be expected to last as long as one placed on a pavement in good condition. Similarly, a thin overlay placed on a pavement in good condition but with heavy traffic would not be expected to last as long as one placed on the same pavement but with much lighter traffic.

Numerous factors influence the cost of open graded thin overlays. Several of the factors contributing to the cost of placing these overlays include:

- Materials (binder and aggregate with or without modifiers).
- Location of the project (e.g., urban versus rural area, proximity to hot mix plant, etc.).
- Thickness of the overlay.
- Special construction requirements.

Chapter 3 (Framework for Treatment Selection) provides a simplified method of comparing cost effectiveness of different treatments.

10.3.4 Open-Graded Overlays Mix Design and Specifications

Caltrans uses CT 368 to design OGFC mixes. The California method was revised in 2002 and is based on an aggregate grading designed to give a minimum of 18% voids using CT 367, and a drain down test (CT 368). This test determines the optimum level of conventional binder that may be used without excessive drain down in transportation or during placement of the mixture. When utilizing a modified binder, the OBC is determined by measuring the drain down using the appropriate unmodified binder for the project location. In high binder open graded mixes only asphalt rubber binders are used and the binder content is adjusted upwards by 1 to 2% based on the field experience with these mixtures.

Materials Requirements

More detailed information on the materials requirements for binders and aggregates is covered in Chapter 2. The special requirements of OGFC mixtures are related to its specific properties. The void structure must remain intact to ensure that it remains permeable. As air can penetrate easily and promote aging, the void structure itself will promote accelerated aging compared with dense graded materials. For this reason, the binders used in OGFC mixtures must be more resistant to the effects of aging than those used for HMA mixtures. Modified binders and asphalt rubber provide improved resistance to aging.

The texture of the mixture at the surface affects skid resistance. To achieve this, the aggregate should be hard and abrasion resistant and the mixture must be resistant to permanent deformation so that the open void structure remains intact. The requirements for aggregates were shown in Table 10-5 and the gradings were shown in Table 10-6. It has been found that coarser gradings give a more open void structure (Hicks, 2000, Mallick, 2000). These tend to give good stone on stone contact and deformation resistance and the voids are less susceptible to becoming clogged.

Binders for OGFC include PG 64-10, PG 64-16, PG 64-28, PG 70-10, and Asphalt Rubber (Caltrans, 2007). Modified systems such as asphalt rubber can be used to address low temperature cracking, reflective cracking and night paving. Polymer modified binders (PG PM) may be used to address low temperature cracking and to overcome problems of lower temperature paving conditions (e.g., night paving). Binder requirements are shown in Table 10-7. The void structure allows absorption of free surface asphalt to overcome bleeding pavements. Since durability is a function of film thickness (Shell, 1999), the use of modifiers that increase in-service viscosity allow for thicker films and higher resistance to oxidation and raveling (Lender, 2001). All modifiers appear to improve the abrasion resistance of the mixes (Mallick, 2000).

It has been found in various studies that modified binders give superior service lives as they prevent binder drain down in application and in service (Smith, 1993; Schuler, 1994). This is due to the elastomeric nature of the binders that resists flow at even high production and service temperatures. They also improve rutting resistance and are less thermally susceptible.

Table 10-6 Aggregate Gradation Requirements (Caltrans, 2007)

1–inch OGFC

Sieve Sizes	Target Value Limits	Allowable Tolerance
1 1/2"	100	—
1"	99 - 100	TV ±5
3/4"	85 - 96	TV ±5
1/2"	55 - 71	TV ±6
No. 4	10 - 25	TV ±7
No. 8	6 - 16	TV ±5
No. 200	1 - 6	TV ±2

1/2–inch OGFC

Sieve Sizes	Target Value Limits	Allowable Tolerance
3/4"	100	—
1/2"	95 - 100	TV ±6
3/8"	78 - 89	TV ±6
No. 4	28 - 37	TV ±7
No. 8	7 - 18	TV ±5
No. 30	0 - 10	TV ±4
No. 200	0 - 3	TV ±2

3/8–inch OGFC

Sieve Sizes	Target Value Limits	Allowable Tolerance
1/2"	100	—
3/8"	90 - 100	TV ±6
No. 4	29 - 36	TV ±7
No. 8	7 - 18	TV ±6
No. 30	0 - 10	TV ±5
No. 200	0 - 3	TV ±2

Mix Requirements

Table 10-7 shows binder materials typically used by Caltrans.

Table 10-7 Asphalt Binder Selection (Caltrans, 2007)

<table>
<tr><th rowspan="2">Binder

Climatic Region</th><th colspan="2">Conventional Asphalt</th><th>Rubberized Asphalt</th></tr>
<tr><th>PG</th><th>PG Polymer Modified(1)</th><th>PG</th></tr>
<tr><td>South Coast
Central Coast
Inland Valleys</td><td>64-10</td><td rowspan="5">58-34PM</td><td rowspan="3">64-16</td></tr>
<tr><td>North Coast</td><td>64-16</td></tr>
<tr><td>Low Mountain
South Mountain</td><td rowspan="2">64-28</td></tr>
<tr><td>High Mountain
High Desert</td><td>58-22</td></tr>
<tr><td>Desert</td><td>70-10</td><td>64-16</td></tr>
</table>

Note: (1) For low temperature placement

10.3.5 Open-Graded Overlays Construction

Manufacturing and construction methods are similar to those for dense graded materials. The methods must address the following important issues (Hicks, 2000).

Safety

Standard Caltrans safety and traffic control procedures must be followed. These procedures are detailed in Caltrans references (1999 and 2003).

Manufacture

No specific modifications are required to plants. Binder tanks should have agitation, especially if asphalt rubber binders are used and all limitations must be observed for storage time and temperatures (Caltrans, 2007). Binder proportioning requires a mass flow meter to ensure accuracy.

Appropriate temperatures must be carefully controlled during the mixing process. Temperatures that are too high will promote drain down and 'fat' spots or 'dry' spots in the final surfacing. Temperatures that are too low may result in inadequate coating of the aggregate.

Storage

In general, open graded mixes should not be stored for more than two hours. This is due to the potential for binder drain-down. See Caltrans Standard Specifications Section 39 for details (Caltrans, 2007).

Hauling

Standard transport equipment may be used. Tarping may help prevent loss of heat and crusting of the mixture; especially during night and cool weather work using modified mixes. This is critical for haul times longer than 30 minutes in the daytime and for night work. Release agents may be used on the truck bed. Diesel or other petroleum materials should never be used as release agents since these will soften the mixture. Hauling distance should be as short as possible. Currently no maximum distance has been specified. It should be such that the application temperatures in Table 10-3 are met.

Surface Preparation

This is the same as for dense graded thin overlays.

- Thermoplastic markings should be removed according to Caltrans guidelines.
- All crack and joint sealing should be performed prior to placing the OGFC. Allow for adequate cure time for crack and joint sealants. Hot applied sealants require three to four months while cold applied products require one year.
- Overlay of an existing OGFC surface will require removal of the existing OGFC prior to placing new OGFC. This will prevent water entrapment and poor bonding. This should be considered at the planning stage since this item of work may be a substantial cost to the project. Conformance to current standards and policy for removal and disposal of pavement grindings should be adhered to.

Tack Coat

Good tack coat practices must be followed correctly. (Caltrans, 2007; Caltrans, 2006b). OGFC requires a heavier tack coat than DGAC as the tack coat assists in waterproofing the underlying pavement. If the surface is milled, a heavier than conventional coat will be required to ensure the more absorbent surface is waterproofed.

Laydown

During laydown, standard Caltrans safety and traffic control procedures must be followed. These procedures are detailed in the Caltrans reference (1999). Traffic is not allowed on OGFC until final rolling has been completed.

Paving guidelines shown in Table 10-8 are applicable to the laydown of the OGFC mix.

Table 10-8 Laydown Guidelines

ANTICIPATED AMBIENT TEMPERATURE	GUIDELINES*
> 70ºF	OGFC may be placed using windrow and pick up machines. The length of the windrow should be usually limited to 164 ft. There should be little or no wind
55ºF – 70ºF	OGFC should be placed by end-dumping into the paving machine, not by windrowing. Keep rollers within 49 ft of paving machine. Tarp trucks for hauls >30 minutes. Mix in hopper to be 194-248ºF.
50ºF – 55ºF	In addition to above rules, PG-PM (polymer modified) asphalt binder should be used. Asphalt rubber binders may also be used. Maximum mixing temperature can be raised to 325 ºF. Mix temperature in hopper to be 275ºF.
< 50ºF	OGFC should not be placed.

**Ensure all Standard Specifications and SSPs (Caltrans, 2007) are followed.*

Wind is an important factor. Cold wind may reduce the surface temperature quickly making compaction difficult. On very cool and windy days placement may need to be suspended.

Transverse joints are more difficult to make in open graded mixtures due to these mixtures being more difficult to work by hand as compared with dense graded mixtures. Handwork should be minimized. For this reason, transverse butt joints should be constructed or joints should be avoided by continuous paving. Longitudinal joints are made in a similar manner to those for dense graded mixtures.

Rolling

The rollers used for open graded mixtures are solely steel wheeled operated in static mode (pneumatic rubber tired rollers are not used because they will close up the voids in the surface by kneading action and the mix may stick to the tires). Rolling temperatures are shown in Table 10-9. The entire mat placed by the paving machine must be rolled before it cools. It would be prudent, however, to insure that the roller rolls to the edge only and does not "hang over" an unsupported edge, causing excess weight concentrated on the edge which could collapse the void structure. It should be noted that the recommended weight of rollers for OGAC is steel rollers having a weight of 126-172 pounds per linear inch of compactive force (Caltrans, 2007). They shall be used only in the static mode and limited to two complete coverages. The static weight of the rollers was not used due to the varying widths of rollers available.

Table 10-9 Application Temperatures (Caltrans 2007)

BINDER TYPE	MINIMUM AIR TEMPERATURE, ºF	MIN SURFACE TEMPERATURE, ºF	MINIMUM BREAKDOWN ROLLING TEMPERATURE, ºF	MINIMUM FINISHING TEMPERATURE, ºF
Conventional (Unmodified)	55	60	ASAP (240)	200
PG-PM	50	50	240	180
Asphalt Rubber	55	60	280	250

Sampling and Acceptance

This should be carried out according to Caltrans CT 125. OGFC is usually accepted based on aggregate grading; mix binder content, and visual inspection.

Post Treatment

If traffic can be kept off the mix, no treatment is required. However, in most cases, sanding is carried out on rubberized mixes to prevent initial traffic pick up. Clean sand is spread using a sand spreader at about 1 to 2 lbs/yd^2 after rolling is complete (Caltrans, 2007).

10.4 GAP-GRADED OVERLAYS

Gap graded mixtures currently placed in California are, in general, solely Rubberized Asphalt Concrete (RAC) Type G which uses asphalt rubber binders (Caltrans, 2007). However, MB type G mixtures have been used in pilot projects. This section covers only the RAC-G asphalt rubber mixes.

10.4.1 Gap-Graded Mixes

A gap graded mixture consists of an aggregate grading that has a missing fraction. The Type G gradings are shown in Table 10-10. In California, the gap (missing fraction) is used to accommodate the asphalt rubber binder. This is intended to allow for stone on stone contact for deformation resistance and the extra binder has been found to aid in fatigue and reflection cracking resistance. The CRM increases the viscosity of the binder allowing high binder contents without bleeding. The increase in voids allows the mix to accommodate the larger particulate rubber present in asphalt rubber binders (Hicks, 2000). The binder content may be 7 to 9% by weight with asphalt rubber binders.

Table 10-10 Rubberized Hot Mix Asphalt - Gap Graded (Caltrans, 2007)

3/4" RHMA-G

Sieve Sizes	Target Value Limits	Allowable Tolerance
1"	100	—
3/4"	95 - 100	TV ±5
1/2"	83 - 87	TV ±6
3/8"	65 - 70	TV ±6
No. 4	28 - 42	TV ±7
No. 8	14 - 22	TV ±5
No. 200	0 - 6	TV ±2

1/2" RHMA-G

Sieve Sizes	Target Value Limits	Allowable Tolerance
3/4"	100	—
1/2"	90 - 100	TV ±6
3/8"	83 - 87	TV ±6
No. 4	28 - 42	TV ±7
No. 8	14 - 22	TV ±5
No. 200	0 - 6	TV ±2

The purpose of gap grading is to provide improved stone-to-stone contact by reducing the fine aggregate content so as to provide a strong aggregate skeleton that creates space for more engineered binder than a dense graded mix can hold. Gap grading is also a good way to increase the VMA of a mixture.

Stone matrix asphalt (SMA), also a gap graded mixture, uses fibers to prevent drain-off. The modifier used in these mixtures makes the binder thick enough to stay in the matrix so that binder content may be higher than that for a dense graded mix. Voids characteristics of gap graded mixtures should be similar to those of DGAC, although VMA can be somewhat higher.

10.4.2 Gap-Graded Overlays Performance

Distresses/Conditions Addressed

Thin gap graded thin overlays should be placed on structurally sound pavements. They can be used to mitigate the following distresses present in an existing pavement:

- Raveling
- Oxidation
- Reflection cracking
- Minor surface irregularities
- Flushing surfaces
- Skid problems

Although not as free draining as open graded mixes, some improvement is noted in skid related problems (i.e., hydroplaning and spray and splash) and noise reduction.

Principle Distress Modes

Type G thin overlays can exhibit the following distress modes:

- Permanent deformation due to heavy traffic and high temperatures.
- Shear failures in high stress areas.
- Fatigue cracking due to repeated traffic loading.
- Reflection cracking due to cracks in the existing pavement reflecting up through the overlay.
- Raveling due to a number of factors including oxidation and hardening of the binder, water damage, low binder content, and low compaction.
- Stripping caused by binder to aggregate incompatibility.
- Delamination, due to poor compaction and/or tack coat practice.

Often, these can be addressed by proper mix design and job selection. In California, only asphalt rubber modified binders are used in these mixes.

10.4.3 Gap-Graded Overlays Job Selection

Where Should Gap Graded Asphalt Concrete be Used?

Type G mixes are used as a surface treatment over dense graded asphalt concrete pavements and occasionally on portland cement concrete pavements. It should be placed over structurally sound pavements and may be used in new construction and rehabilitation projects. These mixes are generally used on the traveled way and should be placed across the entire roadbed, from outside edge of shoulder to outside edge of shoulder to provide uniform frictional properties and proper drainage. Properly designed and constructed type G mixtures have low permeability and have good durability characteristics (due to high binder content).

Where Should Gap Graded Asphalt Concrete Not be Used?

Type G mixes should not be used on unsound pavement exhibiting substantial cracking, rutting, bleeding, or depressions. The extent of pavement distress precluding the use of these mixes has not been quantified at this time. Type G should not be considered for use on bridge decks as a surface course unless approved by Headquarters Structures Department.

Service Life and Costs

Costs of Type G mixes are higher than OGFC. Caltrans has not performed any LCCA on these mixes.

10.4.4 Open-Graded Overlays Design and Specifications

The design of Type G mixtures is similar to that for dense graded mixtures as indicated in SSP 39-400 (Caltrans, 2007) except that CT 367 is modified in the following ways:

- The aggregates must have a grading and quality resulting in a mixture containing 7 to 9% asphalt rubber binder by weight of dry aggregate.
- The air void content used to select the optimum binder content varies according to traffic index (level) and climatic region as detailed in SSP 39-400 (Caltrans, 2007).
- Laboratory mixing is done from 300 to 325°F (149 to 163ºC) and compaction from 290 to 300°F (143 to 149ºC)
- A minimum stabilometer value of 23 (CT304 and 366) is required.

- A minimum VMA of 18% is required as determined by the test described in Asphalt Institute Mix Design Methods for Asphalt Concrete (MS-2) (Asphalt Institute, 1988).

Asphalt rubber materials requirements are provided in Chapter 2. The aggregate for Type G rubberized asphalt concrete shall conform to the grading contained in SSP 39-400 (Caltrans, 2007) and shall meet the quality provisions specified for Type A asphalt concrete in Section 39-2.02, "Aggregate," of the Standard Specifications (Caltrans, 2007).

10.4.5 Gap-Graded Overlays Construction

Construction methods for Type G mixtures are similar to those for dense graded materials as detailed in Section 10.2.5. The following are important issues (Hicks, 2000).

Safety

Standard Caltrans safety and traffic control procedures must be followed. These procedures are detailed in Caltrans references (1999 and 2003).

Manufacture

No specific modifications to plants are required. Binder tanks require agitation, especially if asphalt rubber binders are used and all limitations must be observed on storage time and temperatures (Chapter 2 and Caltrans, 2007).

Mixing temperatures must be in the correct range to allow full coating of the aggregates. Temperatures that are too low do not allow adequate coating of the aggregates whereas temperatures that are too high can result in smoke or excess fumes.

Storage

In general, Type G mixes should not be stored for more than two hours due to stability limitations in the asphalt rubber binder.

Hauling

Standard hauling equipment (i.e., end dump vehicles) may be used for the construction of Type G overlays. Caltrans reference (2003) contains further information regarding on these types of vehicles. Tarping may help to prevent temperature loss and crusting of the mixture (i.e., hardening of the first few centimeters of the mixture exposed to ambient temperatures); especially in night and cool weather work with modified mixes. Release agent may be used on the truck bed. On no account should diesel or other petroleum materials be used as release agents as these will soften the mixture.

Surface Preparation

This is the same as for dense graded thin overlays. Where agriculture product drippings are an issue, flushing is an option. It needs to be completed 24 hours in advance of the overlay to allow drying time. When cracks are being treated, especially fatigue cracks, a membrane or SAMI may be used as a surface preparation. Membranes may also be used to waterproof the underlying layer.

Tack Coat

Good tack coat practice must be followed. The Standard Specifications (Caltrans, 2007) and Caltrans Tack Coat Guidelines (Caltrans, 2006b) specify how to apply tack coats in a manner satisfactory to Caltrans. Surfaces must be clean before the tack coat is applied. If a good bond is not formed between the thin overlay and the existing pavement, it can de-bond resulting in a slippage failure or delamination. If too much tack coat is applied, it may bleed up through the layer, especially under heavy traffic.

Laydown

Type G mixes may be windrowed ahead of the paver and picked up with a pick up device (loader) and deposited in the paver hopper. The length of the windrow must be as short as possible to ensure excessive cooling does not occur. If conditions are good (i.e., little or no wind and higher temperatures), this is usually about 160 ft (50 m) maximum (Hicks, 2000). If conditions are poorer than this, the length of the windrow should be kept shorter than 160 ft (50 m). Table 10-11 summarizes minimum application temperatures for the various stages of the construction process. Every effort should be made to avoid segregation of the mixture during the paving operation. In addition, mix that is left in the paver hopper too long and, thus, allowed to cool below the minimum laydown temperature should not be combined with fresh mix.

Table 10-11 Recommended Application Temperatures (Caltrans, 2007)

MATERIAL	MINIMUM AIR TEMPERATURE, °F	MINIMUM MIX LAYDOWN TEMPERATURE, °F	MINIMUM BREAKDOWN ROLLING TEMPERATURE, °F	MINIMUM FINISHING TEMPERATURE, °F
Asphalt Rubber	55 to 65	290	260	203
	≥ 65	280	250	203

These are minimum temperatures. It is recommended that spreading and compacting be performed at temperatures above these minimums, but not to exceed 325ºF.

Transverse joints are more difficult to construct in Type G mixtures due to the lower workability by hand of such mixes as compared dense graded mixtures. Handwork should be avoided if possible, however, if required handwork should be done as soon as possible. For this reason transverse joints should be constructed as a butt joint or avoided by continuous paving. Longitudinal joints are made in a similar manner to dense graded mixtures (See section 10.2.5 Laydown).

Rolling

Static steel wheeled rollers should be used on Type G mixtures. Pneumatic rubber tired rollers are not allowed as the mix will stick to the tires. The ballasted weight should be no more then 8 to 9 tons (7,000 to 8,000 kg). Rolling temperatures are shown in Table 10-11.

Type G mixes often require more compactive effort than dense graded mixes, and vibratory compaction is generally required for breakdown rolling. The breakdown roller should follow as closely behind the paver as practicable. If the mix is tender, then the roller should lay back only the minimum time necessary for rolling. Breakdown rolling should achieve 90 to 95% of the required compaction. This will ensure that adequate compaction is achieved with the subsequent intermediate roller passes. Finish rolling is mostly for cosmetics. If density has not already been achieved at this stage, additional compaction will likely not increase density due to low mix temperature.

Acceptance

Type G mixes are usually accepted based on grading, binder content, and visual inspection.

Post-Laydown Treatments

If traffic can be kept off the mix, no treatment is required. Otherwise sand conforming to the Standard Specifications Section 90-3.03 (Caltrans, 2007) is applied after final rolling at 1 to 2 lb/yd^2 to avoid pick up by early traffic. Sweeping may be required after initial trafficking to remove the sand. This is generally done the next day.

10.5 TROUBLESHOOTING AND FIELD CONSIDERATIONS

10.5.1 Troubleshooting Guide

This section provides information to assist maintenance personnel with troubleshooting problems associated with placing any of the thin HMA overlays. Table 10-12 presents a troubleshooting guide that associates common problems to their potential causes, whereas Table 10-13 lists some commonly encountered problems and their recommended solutions.

Table 10-12 Troubleshooting Guide

Cause	Problem																
	Wavy Surface - Short Waves/ Ripples	Wavy Surface - Long Waves	Tearing of Mat - Full Width	Tearing of Mat - Center Streak	Tearing of Mat - Outside Streaks	Mat Texture - Nonuniform	Screed Marks	Screed Not Responding To Correction	Auger Shadows	Poor Precompaction	Poor Longitudinal Joint	Poor Transverse Joint	Transverse Cracking (Checking)	Mat Shoving Under Roller	Bleeding or Fat Spots in Mat	Roller Marks	Poor Mix Compaction
Fluctuating Head of Material	✔	✔				✔					✔						
Feeder Screws Overloaded	✔	✔				✔			✔								
Finisher Speed Too Fast	✔				✔												
Too Much Lead Crown in Screed					✔												
Too Little Lead Crown in Screed				✔													
Overcorrecting Thickness Control Screws	✔										✔						
Excessive Play in Screed Mechanical Connection	✔	✔					✔	✔				✔					
Screed Riding on Lift Cylinders	✔	✔				✔		✔		✔	✔	✔					
Screed Plates Worn Out or Warped			✔	✔	✔	✔											
Screed Plates Not Tight	✔					✔		✔				✔					
Cold Screed			✔	✔	✔	✔											
Moldboard on Strikeoff Too Low					✔												
Running Hopper Empty Between Loads		✔				✔											
Feeder Gates Set Incorrectly		✔		✔	✔												
Kicker Screws Worn Out or Mounted Incorrectly				✔													
Incorrect Nulling of Screed												✔					
Screed Starting Blocks Too Short												✔					
Screed Extensions Installed Incorrectly					✔	✔											
Vibrators Running Too Slow						✔				✔							

Table 10-12 Troubleshooting Guide (Continued)

Cause	Problem																
	Wavy Surface - Short Waves/Ripples	Wavy Surface - Long Waves	Tearing of Mat - Full Width	Tearing of Mat - Center Streak	Tearing of Mat - Outside Streaks	Mat Texture - Nonuniform	Screed Marks	Screed Not Responding To Correction	Auger Shadows	Poor Precompaction	Poor Longitudinal Joint	Poor Transverse Joint	Transverse Cracking (Checking)	Mat Shoving Under Roller	Bleeding or Fat Spots in Mat	Roller Marks	Poor Mix Compaction
Grade Control Mounted Incorrectly	✔	✔						✔			✔						
Grade Control Hunting (Sensitivity Too High)	✔										✔						
Grade Control Wand Bouncing on Reference	✔										✔						
Grade Reference Inadequate	✔	✔															
Sitting Long Period Between Loads		✔				✔											
Improper Joint Overlap											✔						
Improper Mat Thickness for Max. Agg. Size			✔			✔		✔		✔							
Trucks Bumping Finisher		✔					✔										
Truck Holding Brakes		✔					✔										
Improper Base Preparation	✔	✔				✔				✔			✔	✔		✔	✔
Improper Rolling Operation	✔										✔	✔	✔	✔		✔	✔
Reversing or Turning Too Fast of Rollers		✔												✔		✔	✔
Parking Roller on Hot Mat		✔														✔	✔
Improper Mix Design (Agg)	✔		✔			✔			✔				✔	✔	✔		✔
Improper Mix Design (Asphalt)	✔		✔			✔			✔				✔	✔	✔		✔
Mix Segregation	✔	✔	✔			✔			✔								
Moisture in Mix			✔										✔	✔	✔		✔
Variation of Mix Temperature	✔	✔	✔			✔		✔					✔	✔	✔	✔	✔
Cold Mix Temperature			✔	✔	✔	✔		✔		✔	✔	✔					✔

1.Find problem above
2. checks indicate causes related to paver
X's indicate other problems to be investigated.

Note: Many times a problem can be caused by more than one item, therefore, it is important that each cause listed is eliminated to assure solving the problem.

Table 10-13 Common Problems and Related Solutions

PROBLEM	CAUSES AND SOLUTIONS
Surface Waves	**CAUSES** • A fluctuating head of material in front of the paver screed causing it to rise and fall usually causes surface waves • Worn or badly set screeds can cause surface waves • A mix that is too stiff or that has cooled too much before compaction will cause surface waves • Long waves can be caused by adjusting the screed too often and not allowing an adjustment to fully take effect before changing it again • Dump trucks bumping the paver when delivering a load of mix can cause long waves **SOLUTIONS** • The solution for avoiding surface waves is to control the material amount, temperature, and screed correctly • Pave continuously with a pick up machine where possible
Wash Boarding	**CAUSES** • Wash boarding is caused by improper use of vibratory rollers, either in amplitude setting or in speed of roller **SOLUTIONS** • Use higher roller amplitudes for thicker layers and lower amplitudes for thinner layers • Slow down the roller
Tearing	**CAUSES** • Poor paver operation, or the mix being too cold and/or too stiff causes tear marks **SOLUTIONS** • Tear marks can be avoided by adjusting the degree of crown and ensuring the mix temperature is correct

Table 10-13 Common Problems and Related Solutions

PROBLEM	CAUSES AND SOLUTIONS
Non Uniform Texture-Segregation	**CAUSES** • The mixture separating in the hopper or in transportation causes segregation • Poor paver set up • Low mix temperature or poor grading or mix design • Prone to occur in thin overlays • Weak base layer. • The dumping of hopper wings when paving with bottom dumps **SOLUTIONS** • Ensure thickness is at least three times that of largest stone size, mix design is correct, and the paver is properly set up • Ensure mix temperature is correct • Not dump the wings or, alternatively, place insert plates in the hopper eliminating the wing area
Screed Marks	**CAUSES** • Transverse screed marks occur when the paver stops and starts and longitudinal screed marks occur when extensions are used on the screed • Poor paver set up or worn or dirty screeds • Low mix temperature or poor grading or mix design **SOLUTIONS** • Set paver and screed correctly. Use windrowing to ensure paver does not stop • Ensure the mix is in specification
Surface Shadows	**CAUSES** • Caused by overloading augers in the paver • May be caused by low mix temperature or poor grading or mix design **SOLUTIONS** • Adjust the distance between the screed and the tractor of the paver • Ensure that the level of mix is near the center of the auger shaft. The augers should NOT be totally covered with mix

Table 10-13 Common Problems and Related Solutions

PROBLEM	CAUSES AND SOLUTIONS
Roller Checking and Roller Marks	**CAUSES** • Deflection under the roller (i.e., mix too hot) or mix design is poor • Too much asphalt in the mix, too much middle size sand in the gradation (No. 16 - No. 30 [1.18mm - 600 µm sieve]) **SOLUTIONS** • Wait until the mix cools further or adjust the mix design
Bleeding and Fat Spots	**CAUSES** • High mix temperature or poor grading or mix design • Too much asphalt in the mix or amount of fines too low in the grading • Mix design not taking the correct traffic level into account • Moisture in the mix or on the pavement • Extremely high applications of tack coat • Existing bleeding surface **SOLUTIONS** • Solve by ensuring aggregates are dry during the mixing process, that pavement is not bleeding, that pavement is dry, and that mix is correctly designed for traffic and aggregate
Shoving	**CAUSES** • Caused by excess asphalt in the mix • Improper roller operation such as sudden reversal • Rolling before the mat is stable enough • Roller going too fast **SOLUTIONS** • Ensure mix is at correct temperature • Ensure roller is not going too fast • Check and correct mix design if necessary • Consider use of modified binders

Table 10-13 Common Problems and Related Solutions

PROBLEM	CAUSES AND SOLUTIONS
Delamination	**CAUSES** • Insufficient tack coat • Mix is too cold during compaction • Existing surface being too cold for paving • Dirty surface on which an overlay is being placed **SOLUTIONS** • Ensure paving temperatures are correct • Ensure the surface is substantially free of debris
Poor Joints	**CAUSES** • Paver operating at different elevations when paving adjacent lanes • Poor joint practice, especially in compaction of thin layers **SOLUTIONS** • Make sure joints are correctly formed and compacted at the correct temperature
Raveling	**CAUSES** • Insufficient asphalt in the mix • Poor compaction **SOLUTIONS** • Ensure mix design conforms to the specification • Ensure compaction is carried out at correct temperatures

10.5.2 Field Considerations

The following field considerations are a guide for the important aspects of performing a maintenance overlay project. The various tables list items that should be considered in order to promote a successful job outcome. As thoroughly as possible, the answers to these questions should be determined before, during, and after application. The staff to do this work will vary by job type and size. Some topics may need attention from several staff members. The field maintenance personnel should at least be acquainted with its contents. The intention of the tables is not to form a report, but to bring attention to important aspects and components of the project process. Some information is product specific and contained in the relevant standard specifications, special standard provisions, or special provisions.

PRELIMINARY RESPONSIBILITIES	
PROJECT REVIEW	• Is the project a good candidate for a thin overlay? • How much rutting is present, depth and extent? • Other profile problems observed? • How severe and what type of cracking exists? • Is crack sealing needed? • Is the pavement surface waterproof? • How much bleeding or flushing exists? • Is pavement raveling or oxidized? • What is the traffic level? • Is the base sound and well drained? • Is a drainage layer required? • Is pavement strengthening required? Use a structural overlay if it is. • Review project for bid/plan quantities.
DOCUMENT REVIEW	• Application specifications and special provisions • Mix design information • Traffic control plan (TCP)
MATERIALS CHECKS	• A full mix design has been done for the mixture? • The mix is produced by an approved source? • Has the tack coat emulsion been sampled and submitted for testing? • Aggregates meet all specifications and are not from a source known to have stripping problems? If so, what anti stripping treatment is to be used? • Aggregate is clean and free of deleterious materials and correct grading? • Is the tack coat emulsion properly prepared (diluted) before use? • Is the mix checked at the plant for temperature compliance and have samples been taken?

INSPECTION RESPONSIBILITIES	
SURFACE PREPARATION	• Is the surface clean and dry? Has it been swept? • Have any areas with oily residue been scrubbed from the pavement? • Have all pavement distresses been repaired? • Has the existing surface been inspected for drainage problems? • Have all utilities been raised or masked?
EQUIPMENT INSPECTION CONSIDERATIONS	
BROOM	• The bristles are the proper length? • The broom can be adjusted vertically to avoid excess pressure?
TACK COATER	• Is the machine fully functional? • Has the machine been calibrated to accurately spray the correct level of tack coat? • Are all spray tips clean and not blocked? • Are nozzles angled correctly (approximately 30°)? • Is the spray bar at the correct height? Is there a double or triple overlap of spray fan?
PAVING MACHINE	• Is the machine fully functional? • Is the paver clean and are the wings operating correctly? • Are flow gates clear, set at the right height, and functioning properly? • Are the conveyors functioning? • Are the augers clean and functioning? • Is the flow system (manual or automatic) operational? • Are material levels in the paver auger chamber set correctly? • Do the screed heaters work? • Is the screed clean and properly set? Is the angle of attack correct? • Is the automatic leveling system working and correctly set? • Is the paver speed correct for correct thickness and angle of attack? • Are the screed strike offs clean and providing a uniform mat? • In continuous jobs, is the pick up machine working correctly? • Is a materials transfer device being used? Is it working correctly? • Are the mixing and heating facilities fully operational?

EQUIPMENT INSPECTION CONSIDERATIONS	
ROLLERS	• What types of rollers will be used on the project for break down and finish rolling? • Tandem or vibratory rollers - are they fully functional? CT 109? • Pneumatic roller - is it fully functional and do roller tire pressures comply with the manufacturer's specification? • Do the roller tire size, rating, and pressures comply with manufacturer's recommendations? • Ensure the tire pressure is the same on all tires. • All tires should have a smooth surface.
DUMP TRUCKS	• What types of dump trucks are being used? • Are bottom dump trucks providing a clean and well-shaped windrow? • Do rear dump trucks have correct hitch for the paver?
WEATHER REQUIREMENTS	• Have air and surface temperatures been checked at the coolest location on the project? • Do air and surface temperatures meet specification requirements?
DETERMINING APPLICATION RATES	• Have Agency guidelines and requirements been followed? • Is rut filling or a leveling course required? If so, have material quantities been calculated or estimated to properly reprofile roadway? • Has a full mix design been done? • Are tack coat application rates correct for the pavement surface? More emulsion may be required on roads with porous surfaces and less for those with flushed surfaces.
CALIBRATION OF EQUIPMENT	• Are machines calibrated? • Who carried out the calibration and what documentation has been provided?

EQUIPMENT INSPECTION CONSIDERATIONS	
TRAFFIC CONTROL	• The signs and devices used match the traffic control plan. • Flaggers do not hold the traffic for extended periods of time. • Unsafe conditions, if any, are reported to the RE. • The pilot car leads traffic slowly–24 mph (40 kph) or less–over fresh overlays. • Signs are removed or covered when they no long apply.
PROJECT INSPECTION RESPONSIBILITIES	
TACK COAT APPLICATION	• What is the emulsion temperature? • Wind, humidity, and temperature can affect set time and affect distribution. • Has tack coater application spray bar been checked for height, blocked nozzles? • Has application rate been checked? • Has the emulsion been diluted correctly? • Is the grade and ambient temperature satisfactory? • Is the application even and covering the entire pavement? • Is the emulsion allowed to turn black before paving? • Is the application in accordance with Caltrans guidelines? • Do the paver wheels pick up the tack coat during paving?
LAYDOWN OF DENSE GRADED MIX	• Has a test strip been successfully laid and compacted? • Is the ambient and grade temperature correct? • Is the mix temperature correct? • Is the paver going at a uniform speed? • If continuous application is used with windrowing? Is the mixture the correct temperature? • If back dump trucks are used, are changeovers smooth causing no bumping of the paver? • Are the hopper, augers, and screed operating correctly? • Is the screed set at the correct height? • Is the mat being tamped uniformly and is the mat a uniform thickness? • Are height adjustments minimal? • Are height adjustments allowed sufficient times to be effective? • Is the mat uniform looking? • Are edge lines and joint overlaps neat and straight? • Is the job stopped if problems persist?

PROJECT INSPECTION RESPONSIBILITIES	
LAYDOWN OF RAC TYPE G MIX	• Has a test strip been successfully laid and compacted? • Is the ambient and grade temperature correct? • Is there evidence of significant drain down of the mix? • Is the mix temperature correct? • Is the paver going at a uniform speed? • Are the paver wings kept open to avoid segregated mix being laid? • If back dump trucks are used, are changeovers smooth causing no bumping of the paver? • Are the hopper, augers, and screed operating correctly? • Is the screed set at the correct height? • Is the mat being tamped uniformly and is the mat a uniform thickness? • Are height adjustments minimal? • Are height adjustments allowed sufficient times to be effective? • Is the mat uniform looking? • Are edge lines and joint overlaps neat and straight? • Is the job stopped if problems persist? • Does the material have a dull or shiny look?
LAYDOWN OF OPEN GRADED MIX	• Has a test strip been successfully laid and compacted? • Is the ambient and grade temperature correct? • Is the mix temperature correct? • Is there evidence of drain down? • Is the paver going at a uniform speed? • If continuous application is used with windrowing, is the mixture the correct temperature? • If back dump trucks are used, are changeovers smooth causing no bumping of the paver? • Are the hopper, augers, and screed operating correctly? • Is the screed set at the correct height? • Is the mat being tamped uniformly and is the mat a uniform thickness? • Are height adjustments minimal? • Is adjustments allowed time to be effective? • Is the mat uniform looking? • Are edge lines and joint overlaps neat and straight? • Is the job stopped if problems persist?

PROJECT INSPECTION RESPONSIBILTIES	
ROLLING DENSE GRADED MIX	• Has a roller pattern been established? • Have the number of passes required for breakdown rolling been established? • Is the surface temperature of the mat correct at beginning of rolling? • Is the roller being operated at the correct speed? Does the mat check under the roller? • Ensure that no aggregate is crushed under breakdown rolling. • Is water being used to cool the mat? • Is finish rolling required? • How many passes? • Is the mat uniform looking? • Does mat meet density requirements? • Are edge lines and joint overlaps neat and straight? • Is the job stopped if problems persist?
ROLLING RAC TYPE G MIX	• Has a roller pattern been established? • Have the number of passes required for breakdown rolling been established? • Is the surface temperature of the mat correct at beginning of rolling? • Is the roller being operated at the correct speed? • Does the mat check under the roller? If so, wait a little longer for cooling. • Is water being used to cool the mat? • How many passes? • Is the mat uniform looking? • Has density been met? • Does the mix pick up? • Are edge lines and joint overlaps neat and straight? • Is the job stopped if problems persist?

PROJECT INSPECTION RESPONSIBILTIES	
ROLLING OPEN GRADED MIX	• Has a roller pattern been established? • Have the number of passes required for breakdown rolling been established? • Is the surface temperature of the mat correct at beginning of rolling? • Is the roller being operated at the correct speed? • Does the mat check under the roller? If so, wait a little longer for cooling. • Is the mat uniform looking? • Has density been met? • Does the mix pick up? • Are edge lines and joint overlaps neat and straight? • Is the job stopped if problems persist?
TRUCK OPERATION	• Trucks are staggered across the fresh tack coat to avoid driving over the same area. • Trucks travel slowly on the fresh mix. • Stops and turns are made gradually. • Truck operators avoid driving over mat. • Trucks should stagger their wheel paths when backing over a previous pass.
LONGITUDINAL JOINTS	• Is echelon paving used? • Are joints overlapped or cut back? • Has a notch device been used? • Is compaction at joints satisfactory? • If left open to traffic, are edges of runs feathered to prevent fall off of traffic? • Are joints flat and smooth? • How far does the end gate of the paver overlap the previous lane? • Minimal raking of the longitudinal joint should be done. • Compaction should be from the hot side of the joint. • Are the joints straight and compact? • Ensure no gaps!

PROJECT INSPECTION RESPONSIBILITIES	
TRANSVERSE JOINTS	• Transverse joints should be minimal and are used at the end of paving or when problems occur in laying. • Butt joints require a vertical face to be constructed by hand. Is this done? • Is it done quickly to avoid mix cooling? • Compaction is done upstream of the joint, are runoff boards provided for the roller? • Tapered joints are used if traffic is to be carried over a transverse joint. • Is the mat uniform up to the joint? • Is treated paper or sand used on the edge for a temporary joint to form a ramp? • Is a ramp constructed just with mix? • When paving is recommenced, is the ramp or taper removed cleanly? • Is raking used excessively to form the joint? • Is the joint compacted transversely? • If there are restrictions, is the joint compacted longitudinally? • Is the joint tight and well compacted and close to being indiscernible?
BROOMING (IF REQUIRED)	• Brooming begins after the mixture is available for traffic. • Follow-up brooming should be done if raveling is high or if traffic is high.
OPENING THE MIX TO TRAFFIC	• The traffic travels slowly–24 mph (40 kph) or less–over the fresh mat. • Remove all construction related signs when opening to normal traffic.
CLEAN UP	• All loose aggregate should be removed from travel way. • Remove spills from all areas including curbs, sidewalks, and radius applications.

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CHAPTER 11 BONDED WEARING COURSE

11.1 OVERVIEW

A bonded wearing course (BWC) is a gap or open graded, ultra thin hot-mix asphalt (HMA) mixture applied over a thick polymer modified asphalt emulsion membrane. The emulsion membrane seals the existing surface and produces high binder content at the interface of the existing roadway surface and the gap or open graded mix all in one pass. The gap-graded and open-graded mixes provide an open surface texture to allow water to flow through the surface. BWC can be applied and opened to traffic quickly. Bonded wearing courses are primarily used in high traffic areas as a surface treatment over HMA and PCC surfaces. It can be placed over structurally sound pavements as a maintenance treatment, and may also be used in new construction and rehabilitation projects as the final wearing course.

The BWC polymer modified asphalt emulsion membrane seals the existing pavement and bonds the gap graded or open-graded mix to the surface. The thick nature of the membrane allows it to migrate upwards into the mix, filling voids in the aggregate and creating an interlayer of high cohesion that does not delaminate or bleed, when applied correctly.

The BWC gap and open graded mixes provide a stone on stone contact which is resistance to rutting within the mix. The finished mat has very high macro-texture properties, provides good skid resistance, and has a void structure that improves driving visibility by reducing back-spray and tire-splash. The void structure also reduces tire noise. The mix is generally laid two times as thick as the largest stone in the gradation; however, it may be placed thicker to correct minor surface irregularities and as thin as one and a half times the maximum aggregate size.

The BWC process can utilize any one of four different mix types. These include BWC Gap Graded, BWC Open Graded, Rubberized BWC (RBWC) Gap Graded and RBWC Open Graded. BWC Gap Graded consists of polymer modified gap-graded asphalt concrete over a membrane of polymer modified asphalt emulsion. BWC Open Graded consists of open graded polymer modified asphalt concrete over a membrane of polymer modified asphalt emulsion. RBWC Gap Graded consists of gap-graded rubberized hot mix asphalt (RHMA-G) over a membrane of polymer modified asphalt emulsion. RBWC Open Graded consists of open graded rubberized hot mix asphalt (RHMA-O) over a membrane of polymer modified asphalt emulsion.

This document provides an overview of:

- Materials used in construction of bonded wearing courses,
- Guidelines for project selection,
- Construction processes associated with bonded wearing courses,
- Troubleshooting guide to assist the field personnel, and
- Suggested construction field considerations.

11.2 DESIGN AND SPECIFICATIONS

11.2.1 Hot Mix Asphalt

This section provides an overview of materials used in the construction of bonded wearing courses. Bonded wearing courses are constructed using polymer-modified or rubber binders and gap-graded or open-graded aggregates. More detailed information may be found in the Standard Special Provisions SSP 39-700 (Caltrans, 2006c), SSP 39-710 (Caltrans, 2007b), and SSP 39-720 (Caltrans, 2007c).

Binder for BWC Gap Graded

Currently, there are two grades of binder approved in the Caltrans specifications for use in BWC Gap Graded construction. Table 11-1 lists the binder grades and the climatic regions where they are used. For the location of each pavement climatic region, please refer to the Highway Design Manual (HDM) Topic 615 “Climate” (Caltrans, 2006b). The binders vary in their degree of polymer modification, and their use corresponds to the climatic conditions encountered in California. In general terms, PG 76-22 PM is used in hotter climates, while PG 64-28PM is used in cooler climates. The requirements for these binders can be found in Section 92 of the Standard Specifications (Caltrans, 2006d).

Table 11-1 Binder Grades used in Pavement Climatic Regions for BWC Gap Graded

CLIMATIC REGION	PG BINDER GRADE
Desert	PG 76-22PM
South Coast Central Coast Inland Valleys North Coast Low Mountain South Mountain High Mountain High Desert	PG 64-28PM*

Note: (*) Use PG76-22PM on routes with 20 year ESAL’s greater than 10 million (or TI of 12) and where slow moving standing traffic is expected

Binder for BWC Open Graded

The binder for BWC Open Graded is PG 58-34PM regardless of project location.

Binder for RBWC Gap Graded and RBWC Open Graded

The specifications for the rubberized asphalt binder are identical to RHMA-G under Section 39, “Hot Mix Asphalt” of the Standard Specification (Caltrans, 2006d). The base stock for the rubberized asphalt binder is chosen based on Design Information Bulletin (DIB) 86 (Caltrans, 2006a). The climatic regions and the appropriate base stock according to DIB 86 are listed in Table 11-2. RBWC is recommended for use only in those areas of California that frequently place rubberized hot mix asphalt.

Table 11-2 Based Stock used in Rubberized Asphalt (Caltrans, 2006a)

CLIMATIC REGION	BASE STOCK FOR RUBBERIZED ASPHALT
South Coast Central Coast Inland Valleys North Coast Low Mountain South Mountain Desert	PG 64-16
High Mountain High Desert	PG 58-22

Aggregate

The main properties of the aggregate used in BWC mixtures include gradation, shape, number of crushed faces, wear resistance and clay or deleterious material content.

All gradations can be used on high volume roads. Additional characteristics to consider, when choosing a gradation, are listed in Table 11-3. The ½ inch gradation is used where a thicker mat is desirable and where pedestrian or bicycle traffic are not a concern. Mat thickness should be a minimum of 1 inch. The 3/8 inch gradation is most widely used for urban, residential and business district roadways where pedestrian and bicycle traffic is a consideration. This can also be used on mainline travel ways with a minimum thickness of ¾ inch. The No. 4 maximum gradation is used for urban, residential, and business district roadways where pedestrian and bicycle traffic is a consideration. A minimum thickness of 5/8 inch is recommended because this gradation allows for some 3/8" material in the blend.

Table 11-3 BWC and RBWC Gradation Selection Characteristics

	GRADATION		
CHARACTERISTICS	1/2"	3/8"	No. 4(A)
Recommended Lift Thickness	1"	3/4"	5/8"
High Traffic	Excellent	Excellent	Good
City Streets	Excellent	Excellent	Excellent
Residential Streets	Good	Excellent	Excellent
Bicycle Traffic	Fair	Good	Excellent
Pedestrian Traffic	Fair	Good	Excellent
Noise Mitigation	Fair	Good	Excellent
Reflective Cracking Mitigation	Excellent	Good	Fair
Release to Traffic	Excellent	Excellent	Excellent

Note (A): No. 4 gradation only applies to BWC Gap Graded mix

The physical property requirements of the aggregate used in BWC mixtures are prescribed in the respective BWC and RBWC specifications. In mountainess environments with multiple daily freeze thaw cycles, it is recommended to only use BWC Gap Graded or RBWC Gap Graded. For BWC Gap Graded, use only the 3/8" or No. 4 gradation with the modifications for freeze-thaw areas as listed in the SSP. BWC Open Graded and RBWC Open Graded are recommended for use in areas that have frequent or heavy rainfall because their more open texture allows for more water to be removed from the pavement surface.

The aggregate specifications are provided to obtain desired mix properties. For example, the mixture is intended to interlock and develop a shear-resistant pavement surface; hence, crushed particle faces are essential. The gap and open-graded aggregate creates voids in the aggregate, which ensure the correct void level in the mix. Flat or elongated particles reduce texture depth and are to be avoided. The aggregate should also be wear resistant (low wear value in CT 211) and low in clay content (high Sand Equivalent value using CT 217).

Mix Design

The performance of a bonded wearing course depends on the quality of the materials and how they interact during application, rolling, and after opening to traffic. This is heavily dependent on the mix design. The following sections provide a summary of the mix design considerations.

11.2.2 BWC Gap Graded

The amount of polymer modified asphalt binder to be mixed with the aggregate for gap-graded polymer modified asphalt concrete shall be determined by the Contractor using the surface area calculation in Asphalt Institute MS 2 (Table 6.1). Using a 1/2", 3/8", or No. 4 maximum gradation, the optimum binder content shall be established based on an estimated film thickness minimum of 10 microns. Film thickness is calculated based on effective asphalt content. The tensile strength ratio (TSR) is a minimum of 70 as determined by a modified California Test 371. The vacuum saturation portion of the test procedure is modified to account for the gap gradation. If the test results show the minimum tensile strength ratio of the untreated HMA mix to be less than 70, an antistrip treatment, such as lime or liquid, is required and the quantity of the additive should produce a tensile strength ratio of at least 70. The plasticity index of the aggregate blend under California Test 204 is used to determine the appropriate type of antistrip treatment. If the plasticity index is between 4 and 10, either dry hydrated lime with marination or lime slurry with marination can be used. If the plasticity index is less than 4, liquid antistrip, dry hydrated lime without marination, dry hydrated lime with marination, or lime slurry with marination can be used. To complete the mix design with the antistrip treatment included, the appropriate lab procedure is used as listed in the SSP (Caltrans, 2006c). The TSR requirement can be waived by the DME.

11.2.3 BWC Open Graded

The mix design requirements for BWC Open Graded are based on "open graded asphalt concrete" found in Section 39 of the Standard Specifications (Caltrans, 2006d). Using a 1/2" or 3/8" maximum gradation, the optimum bitumen content (OBC) is determined by California Test 368. The aggregate blend should be treated with an antistrip treatment unless the DME waives the requirement.

11.2.4 RBWC Gap Graded

The mix design requirements for RBWC Gap Graded are based on the RHMA-G in Section 39, "Hot Mix Asphalt" of the Standard Specifications (Caltrans, 2006d). Using a 1/2" or 3/8" maximum gradation, the optimum bitumen content is determined by California Test 367 following exceptions as listed in the specification. The tensile strength ratio (TSR) is a minimum of 70% as determined by modified California Test 371. The vacuum saturation portion of the test procedure is modified to account for the gap gradation. If the test results show the minimum tensile strength ratio of the untreated HMA mix to be less than 70, an antistrip treatment, such as lime or liquid, is needed that will produce a tensile strength ratio of at least 70. As discussed above, the plasticity index of the aggregate blend under California Test 204 is used to determine the appropriate type of antistrip treatment. If the plasticity index is between 4 and 10, either dry hydrated lime with marination or lime slurry with marination can be used. If the plasticity index is less than 4, liquid antistrip, dry hydrated lime without marination, dry hydrated lime with marination, or lime slurry with marination can be used. To complete the mix design with the antistrip treatment included, the appropriate lab procedure is used as listed in the SSP (Caltrans, 2007b). The TSR requirement can be waived by the DME.

11.2.5 RBWC Open Graded

The mix design requirements for RBWC Open Graded are based on the RHMA-O section in Section 39 of the Standard Specifications (Caltrans, 2006d). Using a 1/2" or 3/8" maximum gradation, the optimum binder content (OBC) is determined by California Test 368 except that the OBC determined by CT 368 is multiplied by a factor of 1.2. The aggregate blend should be treated with an anti-strip treatment unless the DME waives the requirement.

11.2.6 Polymer-Modified Asphalt Emulsion Membrane

The polymer modified emulsion membrane is designed to give high flexibility and bonding over the range of climactic conditions in which bonded wearing courses are placed. This emulsion is manufactured using conventional means.

Specifications are based on standard emulsion specifications such as, stability, binder content, viscosity and torsional recovery. Application viscosity is important; as the material should be thin enough to be easily sprayed at the correct rate, but thick enough not flow away and form a continuous membrane. The residual properties indicate polymer presence and the base asphalt grade used. The polymer modified asphalt emulsion used is specially formulated for all BWCs and RBWCs. Cooler conditions call for higher residual penetration, while warmer climates require lower residual penetration. Additionally, the emulsion is designed to break rapidly after spraying to ensure that no water is trapped. The gap-graded or open-graded nature of the mix allows water to escape, thus promoting breaking of the emulsion.

11.3 PROJECT SELECTION

11.3.1 Distress and Application Considerations

While a bonded wearing course is a flexible pavement surface, it is not considered a structural layer at the typical placement thickness of less than 1 inch. A BWC is a viable application for treating structurally sound, worn pavements and has shown some ability to retard reflection cracking due to its membrane and gap or open-graded aggregate structure. BWC's are used on both flexible and PCC pavements to correct non-structural surface defects such as skid resistance, noise dampening and splash-and-spray control. They are typically selected for use when speed of construction and user delays are concerns. Table 11-4 outlines the allowable surface distress' on which a BWC can be placed. Note that the definitions of pavement condition in Table 11-4 are taken from SHRP Manual P-338 (SHRP, 1993).

Table 11-4 Distress Severity or Extent That Can Be Treated With a BWC (Koch, 1998)

Pavement Type	Cracking	Patching/ Potholes	Surface Deformation	Surface Defects	Joint Deficiencies
AC	1. Longitudinal & Transverse (Medium) 2. Block (Moderate) 3. Edge (Moderate)	Patches: Moderate Potholes: Moderate	Rutting: <0.5 in Shoving: No	Bleeding Moderate Polished Agg: OK Raveling: Severe	N/A
PCC	1. Corner Breaks (Moderate) 2. Materials Related Distress (Low) 3. Longitudinal (Moderate) 4. Transverse (Moderate)	N/A	Studded tire Or chain wear (Low)	Map cracking and scaling: < 12 yd^2 to 120 yd^2	Spalling: Moderate
Note: For PCC, a BWC will not treat blowups, pumping, faulting of joints, or crack widths > 3/8 in					

11.3.2 Performance

Bonded wearing courses have been estimated to last 7 to 12 years (Oliver, 1999; PennDOT, 2002; Wonson, 1997) or 6 to 10 years on PCC pavements that are 30 or more years old (Corley-Lay, 2007). The main method of failure is surface wear; that is, the surface oxidizes and is abraded over time. Premature failure occurs from placement on pavements with high deflections and cracked surfaces, base failures and delamination which occurs when placed on dirty or poorly prepared surfaces.

The main performance benefits associated with using a BWC are improved skid resistance, reduced traffic noise, improved pavement condition rating and ride quality, spray reduction, and reduced impact of reflection cracking. Figures 11-1 and 11-2 show how the characteristics of a BWC compare with those of other mixture types (Oliver, 1999; PennDOT, 2002; Caltrans, 1998). The figures indicate that a BWC retains good skid resistance characteristics over time and that it is comparable to other wearing courses that provide good skid resistance characteristics. The skid resistance of a BWC varies with increasing speed in a manner similar to stone mastic asphalt as shown in Figure 11-2.

Noise level has been measured to decrease 6.7dB (Corley-Lay, 2007). This is a noticeable improvement to the human ear. This is a similar reduction to Quiet Pavement Pilot Program (QPPP) in Arizona, which reported an average noise reduction of 5 dB in residential neighborhoods (FHWA, 2005).

Pavement condition rating (PCR) and ride quality, measured as International Roughness Index (IRI), were assessed on 4 jointed concrete pavements which were overlaid with BWC. All of these projects had positive improvement in both PCR and IRI regardless of initial condition of the pavement as listed in Table 11-5 (Corley-Lay, 2007).

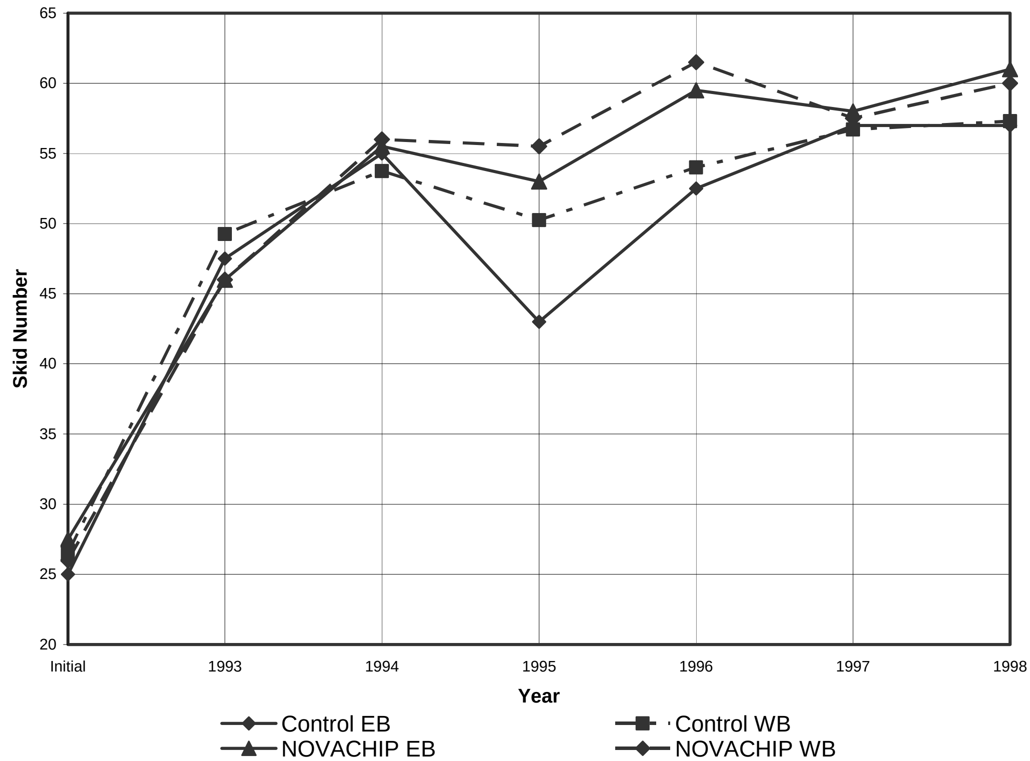

Figure 11-1 Change in Skid Resistance Over Time (Commonwealth PennDOT, 2002)

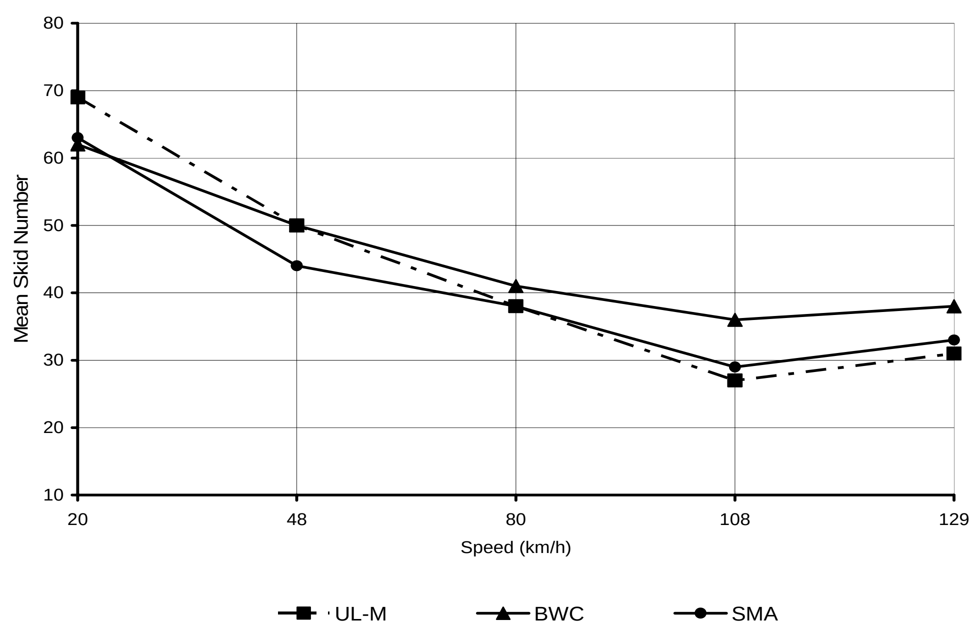

Figure 11-2 Change in Skid Resistance with Speed (Oliver, 1999)

(UL-M is Ultra Thin Polymer Modified HMA – 1 in (25mm))

Table 11-5 Summary of PCR and IRI results for BWC over JCP sections (Corley-Lay, 2007)

SITE	PRE-PCR	INITIAL Δ PCR	POST BWC PCR RATE OF DECLINE (PTS/YR)	PRE-IRI	Δ IRI (DECREASE)	POST BWC IRI RATE OF INCREASE (PTS/YR)
I-40 Burke Eastbound	64.1	35.9	0.83	189.1	103.1	2.1
I-40 Burke Westbound	63.8	36.2	2.47	182.9	99.6	2.1
US 1 Cary	<30.1	>65		201.3	85.4	
I-440 Raleigh Inner	36.6	63.4	3.5	115.2	34.4	1.26
I-440 Raleigh Outer	11.4	88.5	3.2	115.0	32.4	0.54
I-95 Johnston Northbound	33.0	62.0		150.7	62.6	
I-95 Johnston Southbound	37.5	58.2		123.9	40.0	

It can be seen that BWCs rate well in comparison to other surface treatments. The data listed in Table 11-6 has been collected from 2 sources (Oliver, 1999; Holleran, 2001). Splash and spray are important surface characteristics and may be measured in various ways. One method is by hydraulic conductivity. This is done by pressing a special cylinder against the road surface and measuring conductivity. A high number represents faster drainage. Table 11-6 shows the results of hydraulic conductivity tests performed on four surface treatments. As the results indicate, gap-graded BWC had the second highest drainage characteristics of the four surface treatments types tested. Open graded asphalt concrete (OGAC) had the highest drainage characteristic. When spray splash or lateral drainage of the wearing course is a primary concern, BWC Open Graded should be used.

A field comparison of the crack conditions and water permeability of HMA pavement sections treated with a BWC and an open graded friction course (OGFC) in southern Nevada shows that BWC reduces the impact of reflective cracking (Sebaaly, 2007). After 6-years in service, the BWC surface shows significantly less raveling than the OGFC surface. The cracks on the BWC surface are significantly narrower and experience significantly less deterioration than the cracks on the OGFC surface. The BWC membrane provides an effective barrier to moisture penetration through the reflected cracks, thus, reducing the impact of reflective cracking on the performance of HMA pavements. Figures 11-3 and 11-4 demonstrate the difference in the cracking. Another field study shows that reflection cracking appears after a few years on jointed concrete pavements, but the cracks remain narrow and of low severity (Corley-Lay, 2007).

Table 11-6 Hydraulic Conductivity as an Indication of Spray Reduction Characteristics (Oliver, 1999)

MATERIAL	HYDRAULIC CONDUCTIVITY (s^{-1})
0.55 in Stone Mastic Asphalt	0.03
½ in BWC Gap Graded	0.06
0.4 in UL-M	0.01
½ in OGAC	0.12

Figure 11-3 The UTACS cracks remained the same width all through-out the core, except at the membrane which remained sealed although the crack had reflected to the surface (Sebaaly, 2007).

Figure 11-4 The bottom lift of the existing HMA layer is not cracked and the crack on the top layer is very wide at the interface. The crack in the OGFC layer is V shaped, indicative of raveling (Sebaaly, 2007).

Caltrans has placed BWC projects since 2001 in a variety of climates and traffic loadings. These projects total almost 600 lane miles. Figures 11-5, 11-6, 11-7, and 11-8 provide a sampling of the projects placed to date.

Figure 11-5 District 7 Rt. 103, BWC Gap Graded, Constructed in 2005

Figure 11-6 District 6 Rt. 99, The northbound lanes, or right-hand side, are BWC Gap Graded and the southbound lanes are RBWC Open Graded. Constructed in 2005

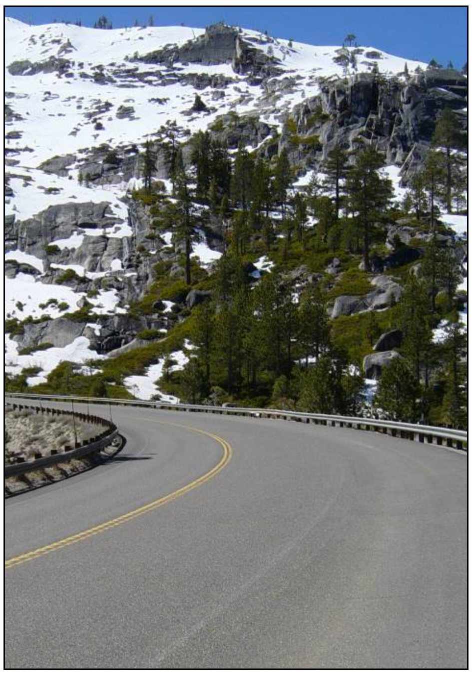

Figure 11-7 District 3 US 50, BWC Gap Graded Alpine mix, Constructed in 2002

Figure 11-8 District 10 I-5, RBWC Open Graded, Constructed 2005

Relative Cost Effectiveness

The oldest projects in the United States, placed in 1993 and 1994 in Pennsylvania, Texas and Louisiana, are still performing well after 14 years. The oldest project in California, placed in 1998, is exceeding the County of Los Angeles' expectations. There has been no observed delamination. Additionally, no maintenance activities have been required on the BWC section of roadway for the past 9 years.

In 2007, BWC total project prices averaged $12 per square yard with the range being between $9 and $14. The high end of this range was seen on projects with limited work windows. Due to the influence on production and the thin application of the HMA, the allowed project work window has one of the largest impacts on project cost. For example, the typical production rate for BWC is 125 tons per hour. On one 2007 project, the contractor was able to pave 1500 tons/day due to a generous work window from 5:00am – 5:00pm. The most expensive projects had work windows that only allowed for 6 hours of production, 11:00 pm until 5:00 am. The contractor still has to pay for an eight-hour shift with only six hours of production. Other factors that influence costs for BWC projects include; materials used, night work vs. day work, quantities, lime treated aggregates, size of project, trucking, and the project location.

Furthermore, BWC is a one-pass process which reduces user delays compared to equivalent two pass processes, such as hot applied chip seal that is followed by an asphalt rubber overlay. User delay costs are included in Life Cycle Cost Analysis. The Caltrans' B/C module estimates user delay costs at $0.17 per delayed minute per car and $0.46 per delayed minute per single unit or combination truck (Caltrans, 2007a).

11.4 CONSTRUCTION

The main components of the construction process include:

- Safety and Traffic Control
- Equipment Requirements
- Mix Production and Handling
- Surface Preparation
- Application Conditions Required
- Application of BWC
- Opening to Traffic

Section 11.5.2, "Suggested Field Considerations", at the end of this chapter, provides a series of tables to guide project personnel through the important aspects of constructing a BWC.

11.4.1 Safety and Traffic Control

Traffic control is required both for the safety of the traveling public and the personnel performing the work. It is also used to ensure the new surface is compacted and allowed to cool to below 160°F prior to reopening the surface to traffic.

Traffic control should be in place before work forces and equipment enters onto the roadway or into the work zone. Traffic control includes placing construction signs, construction cones and/or barricades, flag personnel, and pilot cars required to direct traffic clear of the maintenance operation. For detailed traffic control requirements, refer to the Caltrans project specifications and the Caltrans Code of Safety Operating Practices (Caltrans, 1999).

11.4.2 Equipment Requirements

Equipment requirements for constructing a BWC are found in the appropriate SSPs (Caltrans, 2006c; Caltrans, 2007b; Caltrans, 2007c). The most significant requirement is that the binder application and hot mix spreading function are combined into a single unit. The following section describes the specialized unit while the subsequent sections discuss other equipment requirements.

Paving Unit

The paving unit used for the construction of a BWC is a specially designed and constructed machine. Figures 11-9 and 11-10 show the two models that are currently used by contractors. Note that the spray bar is located behind the paver's tracks, so that the polymer modified asphalt emulsion membrane is applied right in front of the augers. Thus, the emulsion film is not damaged by wheels or crawlers. Figure 11-11 shows a close up of the spray and spreading functions of a BWC paving unit, and Figure 11-12 shows a freshly laid BWC.

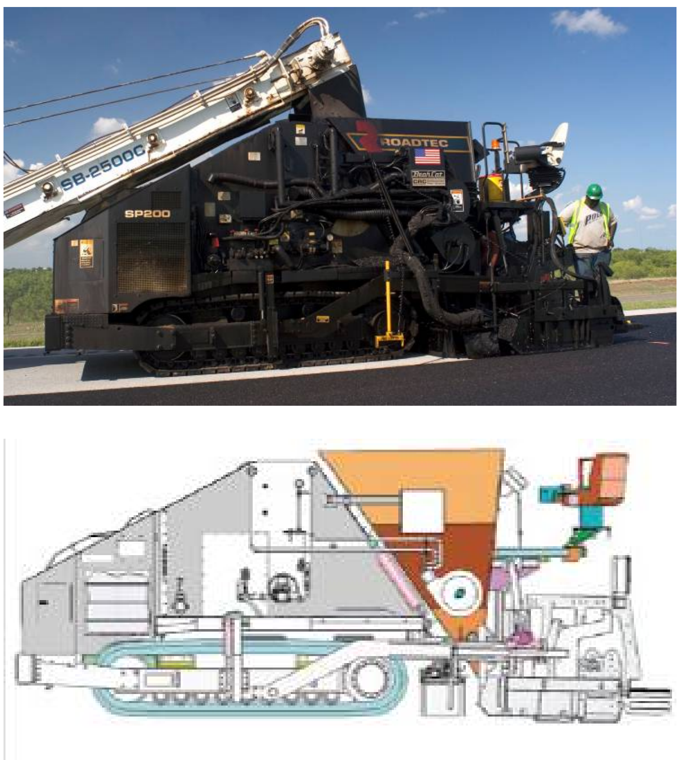

Figure 11-9: Roadtec Spray Paver (Roadtec, 2005)

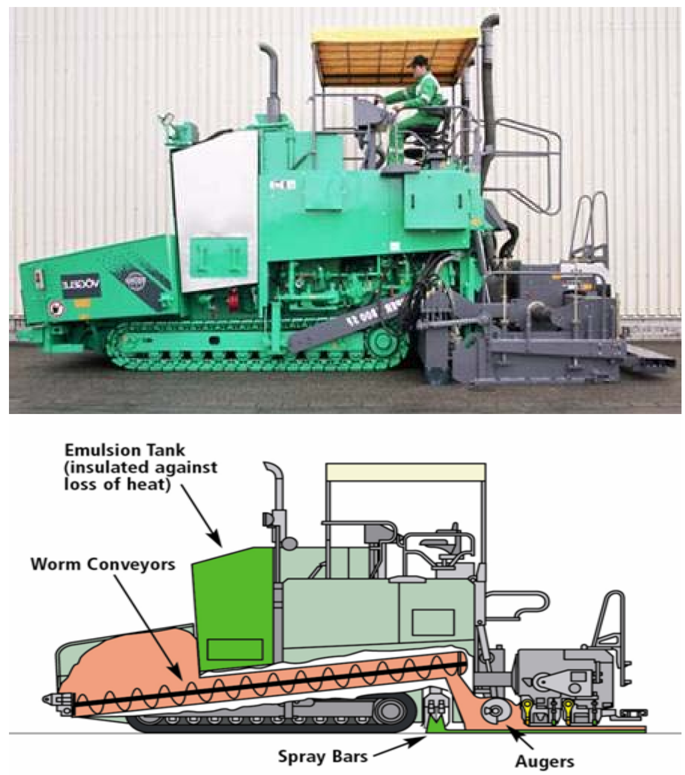

Figure 11-10: Vögele Spray Paver (Vögele, 2004)

- The paving unit pushes the truck carrying the hot mix asphalt.
- The mix drops into a hopper of the paving unit.
- The mix is transported via an auger to a screed.
- The emulsion membrane is sprayed just in front of the screed and the mix is laid on top.

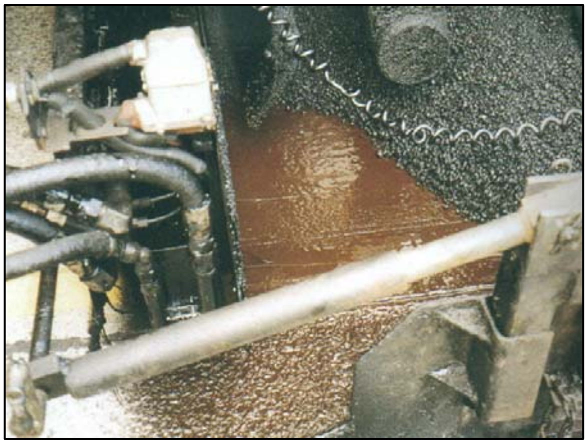

Figure 11-11 Emulsion Membrane and Mix Spreading (Alverez, 1992)

Figure 11-12 Freshly Laid BWC (Alverez, 1992)

11.4.3 Material Transfer Vehicle

A Material Transfer Vehicle (MTV) is not required for construction, but it is highly recommended. It can be beneficial in creating smoother ride with its ability to create a more continuous paving operation. Additionally, it helps keep mix temperature high during cool weather paving such as at night.

It is recommended that a MTV used on BWC projects have the following characteristics:

1. Able to remix the BWC to eliminate truck end segregation, minimize temperature segregation and deliver a uniform BWC to the paver.
2. Be a self-propelled machine totally independent of the paver.
3. Have a high capacity truck unloading system to receive BWC from the haul units.
4. Have a minimum 25 ton on board BWC surge capacity to minimize paver start/stops and maximize trucking efficiency.
5. Be equipped with a pivoting paver loading conveyor able to swing 55 degrees to either side to allow off-lane paving.
6. Paver hopper:
    a. Equipped with a hopper insert, with a minimum capacity of 7 tons.
    b. Hopper insert: Mass flow design to deliver remixed BWC directly to the paver conveyor system.

Rollers

Compaction of a BWC is required. Only static and steel drum type rollers should be used. The rollers must be at least 126 pounds to 172 pounds per linear inch of drum width and must conform to the Caltrans Standard Specifications Section 39-5.02, “Compacting Equipment” (Caltrans, 2006d). Compaction must conform to Caltrans Standard Specifications Section 39-6.03, “Compacting” (Caltrans, 2006d) and shall consist of two coverages. The first before the temperature of the mat falls below 240°F and the second before its falls below 200°F. If necessary, more than 2 coverages may be ordered by the Engineer when rolling bonded wearing course patches or joints. Rolling of the gap-or open graded mixture is intended to seat the aggregates and to provide a smooth surface. There are no in place density requirements when rolling bonded wearing course mixes.

Other Equipment

Other required equipment includes sweepers for cleaning the pavement before application and hand tools such as rakes, shovels etc.

11.4.4 Mix Production and Handling

Standard hot mix facilities and storage bins may be used for BWC mix production, as outlined in Caltrans Standard Specifications 39-3.04, "Mixing" and Section 39-3.01 "Storage", respectively (Caltrans, 2006d). The only special requirements are that the mixing temperatures for a BWC Gap Graded shall not exceed 350°F and storage time shall not exceed 8 hours. The requirements of the other BWC and RBWC are prescribed in the respective specifications. A drain down test should be performed to ensure binder does not drain out of the mixture. All mixing plants must be calibrated to California Test Method CT 109. BWC mixes may be treated with an anti-stripping agent or lime if required, but the District Materials Engineer must approve this.

11.4.5 Surface Preparation

Cracks greater than $^1/_4$ inch wide should be filled or sealed prior to application see Chapter 4 (Crack Sealing, Crack Filling, and Joint Sealing) of this document. The use of over-banding methods of crack sealing is not recommended for this treatment as this method can leave strips that reflect through the finished pavement. All repairs necessary to bring the pavement to the minimum requirements listed in Table 11-9 must also be performed prior to the application of the BWC.

Manhole covers, drains, grates, catch basins, and other utility services must be covered prior protected from the application of the BWC. Covering the services with construction paper or roofing felt can do this. Any surface irregularities deeper than 1 inch should be filled with dense graded hot mix before applying the BWC. Prior to application, the pavement should be swept with a rotary broom equipped with metal or nylon broom stock.

11.4.6 Application

Application of a BWC requires the use of a specialized paving unit described above in Section 11.4.2. Additional details specific to placing bonded wearing courses are discussed in the following paragraphs.

Conditions Required

A BWC may be applied on damp, but not wet, surfaces. The minimum air and pavement temperature requirements are dependent on the type of asphalt binder used. PG 64-28PMs should be placed at temperatures above 45° F, while PG 76-22PMs should be placed at temperature above 50°F. PG 58-34PMs and asphalt rubber binders should be placed above 55° F. The placement temperature may be reduced to 50°F with approval of the Office of Flexible Pavements in METS. No freezing conditions are allowed in the first 24 hours as the polymer modified asphalt emulsion membrane requires about one day to fully cure. If the water in the emulsion freezes, it may rupture the bond between the pavement and the new mix.

Polymer Modified Asphalt Emulsion Membrane

The emulsion applicator is part of the paving equipment and applies the polymer modified emulsion membrane at a temperature between 120° and 180°F at an average rate of 0.20 gal/yd^2. The application rate should be adjusted according to the surface being covered according to tables included in the respective BWC and RBWC specifications (Caltrans, 2006c; Caltrans, 2007b; Caltrans, 2007c). For more absorbent, textured or badly pocked pavement surfaces, the application rate is increased. The application rate is reduced for smooth or flushed AC pavements. Typically PCC pavements require less emulsion membrane than AC pavements.

If the screed extension is outside the spray bar width, the polymer modified emulsion membrane will need to be applied manually to coat the pavement between the end of the spray bar and the end of the screed. Care should be taken to ensure the correct application rate in such circumstances. The spray bar should be calibrated and able to be adjusted to within ± 10% of the design application rate. Coverage of the pavement must be even and uniform and, as such, it is important that there are no plugged nozzles on the spray bar.

Paving

Good paving practice should always be followed when constructing a BWC. Windrowing and pick up machines are not allowed for constructing bonded wearing courses. The trucks servicing the paving unit should operate in a smooth manner, causing no bumps and allow paving to proceed continuously to create a smooth ride.

The minimum delivery temperatures are very critical to successfully place BWCs and RBWCs. Minimum temperature guidelines specified in the respective specifications need to be followed. Placement should not be allowed if BWC and RBWC temperatures behind the screed fall below 285°F due to the propensity of the freshly laid mat to result in shadowing, dragging and raveling.

Longitudinal joints should be straight or correctly aligned to the curvature of the roadway, and should occur only at the edge or center of a traffic lane and never in the wheel paths. Unlike traditional paving, miscellaneous areas, turn lanes, and handwork areas should be paved before paving main line.

Variable width shoulders with a cross slope or grade break in excess of 3% may require different paving techniques. A shoulder backing machine has proven to be very successful using the BWC material. Depending on the project, it can be used to meet grade by paving the main line and then the shoulder or the shoulder and then the main line. Figure 11-13 illustrates this process on State Route 84 near Half Moon Bay.

Figure 11-13 Paving the shoulder of Rt. 84 with BWC Type O using a shoulder backing machine in 2007.

At the start and finish of the work, the existing flexible pavement should be cut out to a depth of 1.2 in and tapered back a distance of 10 ft to provide a key for the new surfacing. For PCC, the mix should be rolled over at the start and finish of the work. The end of each run should be squared off at the point where feathering commences, and the feathered material should be cut out before the next run is started. Figure 11-14 illustrates the method for making transverse butt joints between runs. Handwork should always be minimized.

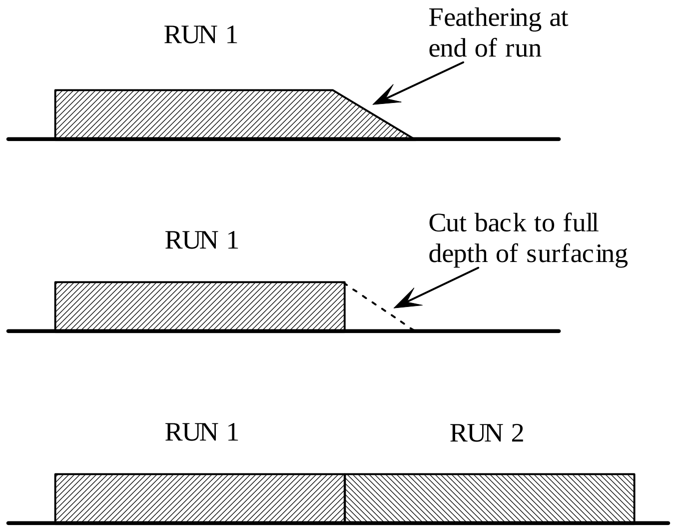

Figure 11-14 Making Transverse Butt Joints (Lobaugh, 1997)

Rolling

A minimum of one steel drum tandem roller is required for compacting a BWC. **Rollers must be operated in static mode only.** Usually two passes using 126 pounds to 172 pounds per linear inch of drum width roller is sufficient to properly seat the aggregates. Rolling must be carried out before the temperature, at mid layer of the mix, falls below 200°F (Caltrans, 2006c). Figure 11-15 shows roller positions relative to the paver.

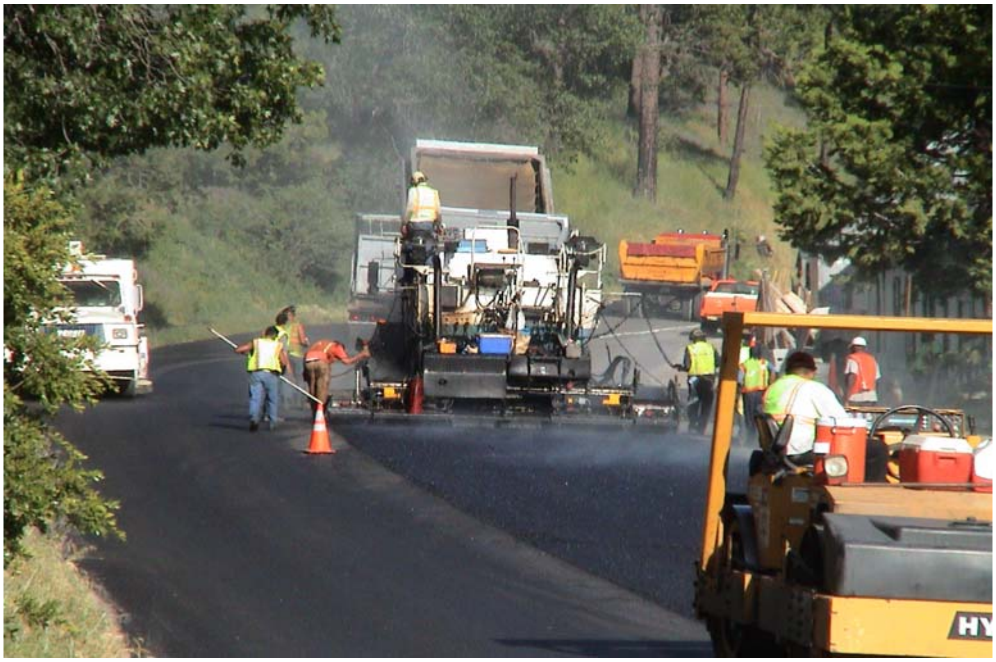

Figure 11-15 Roller Position During Application (Alverez, 1992)

11.4.7 Opening to Traffic

Traffic can be allowed onto the new surface once rolling is completed and the mix temperature has fallen below 160°F. BWC is typically opened to traffic within 15 minutes of placement. RBWC may need to be sanded. If sanded, it is typically opened to traffic within 20 minutes or 30 minutes without sanding. Typically, no post sweeping is required unless the mix begins to ravel or the road is sanded.

11.5 TROUBLESHOOTING AND FIELD CONSIDERATIONS

11.5.1 Troubleshooting Guide

This section provides information to assist the maintenance personnel with troubleshooting problems that may arise when applying a BWC. Table 11-7 lists some commonly encountered problems and their recommended solutions.

Table 11-7 Common Problems and Related Solutions

PROBLEM	SOLUTIONS
SURFACE WAVES	▪ Ensure the head of material in front of the paver screed is at the correct height and does not fluctuate (i.e., rise and fall). ▪ Ensure the screed is not worn or set incorrectly. ▪ Ensure the mix is not too stiff or has not fallen below 285°F. ▪ Ensure the dump trucks do not bump the paving unit as this can cause long frequency waves resulting in increased pavement roughness. ▪ Ensure grade control equipment (if in use) is functioning properly
WASH BOARDING	▪ Slow roller down.
TEARING	▪ Ensure the paving unit is being operated correctly. ▪ Ensure the mix is not too cold (i.e., below 285°F) or too stiff. ▪ May be fixed by adjusting the degree of crown and ensuring mix temperature is correct. ▪ Ensure application is not too thin
NON UNIFORM TEXTURE-SEGREGATION	▪ Ensure the mixture is not separating in the hopper or during transportation. ▪ Ensure the paving unit is set up properly. ▪ Ensure the mix temperature is at least 285°F. ▪ Check the mix design for poor grading. Adjust if necessary.
SCREED MARKS	▪ Ensure the paving unit is set up correctly and that the screed in not worn or dirty. ▪ Ensure the mix temperature is at least 285°F. ▪ Check the mix design for poor grading. Adjust if necessary. ▪ Ensure mix is in specification.
ROLLER CHECKING & MARKS	▪ Ensure the roller does not cause a wave in the mat in front of the roller (i.e., mix too hot). Wait until the mix cools further. ▪ Check the mix design for too much asphalt in the mix, or too much middle size sand in the gradation. Adjust design if necessary.
BLEEDING & FAT SPOTS	▪ Ensure the mix temperature is not too hot (greater than 350°F). ▪ Check the mix design for too much asphalt or for too coarse an aggregate grading. Adjust design if necessary. ▪ Ensure there is no moisture in the mix or on the pavement. ▪ Ensure the tack coat application rate is not too high for the surface to which it is applied. Tight, smooth surface require less tack coat than do more open surfaces. Reduce application rate on existing surfaces that exhibit bleeding. ▪ Ensure spray bar equipment is operating properly. ▪ Ensure aggregates are dry before mixing with asphalt in the hot mix plant, that pavement is not bleeding, that pavement is dry, and that mix is correctly designed for traffic and aggregate.

Table 11-7 Common Problems and Related Solutions (cont.)

PROBLEM	SOLUTIONS
DELAMINATION	▪ Ensure adequate tack coat is applied. ▪ Ensure the mix is above minimum application temperature (285°F). ▪ Ensure the mix is not below the minimum compaction temperature (200°F). ▪ Ensure the existing pavement surface temperature is above the minimum (i.e., 45°F) before paving. ▪ Ensure the surface is cleaned immediately before paving. ▪ Ensure roller drums are not dirty and have working spray systems.
POOR TRANSVERSE JOINTS	▪ Ensure butt joints are properly constructed.
POOR LONGITUDINAL JOINTS	▪ Ensure proper joint construction practices are followed, especially when compacting thin layers.
EXCESSIVE RAVEL	▪ Ensure the mix design meets project specifications, particularly that the mix contains sufficient binder. ▪ Ensure compaction is carried out above the minimum temperature (i.e., 194°F).

11.5.2 Field Considerations

The following field considerations are a guide to the important aspects of applying a bonded wearing course. The tables list items that should be considered in order to promote a successful job outcome. The answers to these questions should be determined, as required, before, during, and after construction. The appropriate staff to do this will vary by job type and size, and some topics may need attention from several staff members. The field supervisor should be acquainted with its contents.

The intention of these tables is not to form a report, but to highlight important aspects and components of the BWC construction process. Some information is product-specific and contained in the relevant standard specifications, special standard provisions, or special provisions.

PRELIMINARY RESPONSIBILITIES	
PROJECT REVIEW	▪ Is the project a good candidate for a bonded wearing course? ▪ How much rutting is present, depth and extent? ▪ How severe and what type of cracking exists? ▪ Is crack sealing needed? ▪ Is the pavement surface waterproof? ▪ How much bleeding or flushing exists? ▪ Is pavement raveling or oxidized? ▪ What is the traffic level? ▪ Is base sound and well drained? ▪ Is surface water splash-and-spray a problem? ▪ Is pavement strengthening required? ▪ Review project for bid/plan quantities.
DOCUMENT REVIEW	▪ Application specifications. ▪ Mix design information. ▪ Special provisions. ▪ Construction manual. ▪ Traffic control plan (TCP).
MATERIALS CHECKS	▪ Have the aggregates been sampled and tested? Do they meet the requirements set forth in the Standard Special Provision? ▪ Has the binder for the mix been sampled and tested? Does it meet the requirements set forth in the Standard Special Provision? ▪ Is the mix produced by an approved source? ▪ Has a full mix design has been performed for the mixture? ▪ Has the mix been tested? Is the mix within specification? ▪ Has the polymer modified asphalt emulsion membrane been sampled and tested? Does it meet the requirements set forth in the Standard Special Provision?
PRE-SEAL INSPECTION RESPONSIBILITIES	
WEATHER REQUIREMENTS	▪ Have air and surface temperatures been checked at the coolest location on the project? ▪ Do air and surface temperatures meet agency requirements? ▪ Is rain expected before or during paving operations? ▪ Are freezing temperatures expected within 24 hours of the completion of any paving runs?
DETERMINING APPLICATION RATES	▪ Agency guidelines and requirements are followed. ▪ Rut filling and leveling course requirements is a separate item and rates have been calculated or estimated to properly re-profile roadway. ▪ Has a full mix design been done? ▪ Are emulsion membrane application rates correct for the pavement surface? ▪ More emulsion may be required on roads with porous surfaces and less for those with flush surfaces or PCC surfaces.

SURFACE PREPARATION	▪ Is the surface clean and dry? Has it been swept? ▪ Have areas with oily residue been scrubbed? ▪ Have all pavement distresses been repaired? ▪ Has the existing surface been inspected for drainage problems? ▪ Have all utilities been raised and masked? ▪ Has project been laid-out to ensure the best possible results?
EQUIPMENT INSPECTIONS	
BROOM	▪ Are the bristles the proper length? ▪ Can the broom be adjusted vertically to avoid excess pressure?
APPLICATION EQUIPMENT	▪ Has the machine been calibrated to accurately spray the correct amount of membrane? ▪ Are all spray tips clean and free of blockage? ▪ Is there a double or triple overlap of spray fan? ▪ Is the paving unit clean and operating correctly? ▪ Are flow gates clear, set at the right height, and functioning properly? ▪ Are conveyors and augers functioning properly? ▪ Is the flow system (manual or automatic) operational? ▪ Are material levels in the auger chamber of the paving unit set correctly? ▪ Do the screed heaters work? ▪ Is the screed clean and properly set? Is the angle of attack correct? ▪ Is the automatic leveling system working and correctly set? ▪ Is the paver speed correct for correct thickness and angle of attack? ▪ Are the screed strike offs clean and providing a uniform mat?
EQUIPMENT INSPECTIONS	
ROLLERS	▪ Are appropriate rollers being used? Do they comply with the requirement set forth in the Standard Special Provisions?
MATERIAL DELIVERY VEHICLE	▪ Do dump trucks or live bottom trailers properly match up with the paving unit?

CALIBRATION OF EQUIPMENT	▪ Are all machines properly calibrated? ▪ Who carried out calibration? ▪ Has documentation has been provided?
PROJECT INSPECTION RESPONSIBILITIES	
TRAFFIC CONTROL	▪ Do the signs and devices used match the traffic control plan? ▪ Does the work zone comply with Caltrans requirements? ▪ Flaggers do not hold the traffic for extended periods of time? ▪ Unsafe conditions, if any, are reported to a supervisor? ▪ Signs are removed or covered when they no longer apply?
EMULSION MEMBRANE APPLICATION	▪ Has the emulsion temperature been checked? ▪ Are high winds expected? Will the expected weather conditions delay the breaking of the emulsion? ▪ Has emulsion application spray bar been checked for blocked nozzles? ▪ Has application rate been checked? ▪ Is the application even and does it cover the entire pavement? ▪ Is the application in accordance with relevant CT guidelines?
PROJECT INSPECTION RESPONSIBILITIES	
LAY DOWN OF BWC GAP GRADED MIX	▪ Has a test strip been successfully laid and compacted? ▪ Is the surface dry (damp is OK)? ▪ Is the mix temperature correct? ▪ Is the paving unit progressing at a uniform speed? ▪ Are the hopper, augers, and screed operating correctly? ▪ Is the screed set at the correct height? ▪ Is the mat being tamped uniformly and is the mat a uniform thickness? ▪ Are height adjustments minimal? ▪ Are height adjustments allowed sufficient times to be effective? ▪ Is the mat uniform looking? ▪ Are edge lines and joint overlaps neat and straight? ▪ Is the job stopped if problems persist?
ROLLING MIX	▪ Is the surface temperature of the mat correct at beginning of rolling? ▪ Is the roller being operated at the correct speed? ▪ Is the mat uniform looking? ▪ When making transverse joints, are they rolled from the cold side first? ▪ Are longitudinal joints rolled from the hot side first? ▪ Are edge lines and joint overlaps neat and straight? ▪ Is the job stopped if problems persist?

TRUCK OPERATION	▪ Do truck operators avoid driving over mat? ▪ Do truck operators allow the paving unit to push the truck? ▪ Are changeovers of dump trucks smooth, causing no bumping of the paving unit?
LONGITUDINAL JOINTS	▪ Are joints matched properly? ▪ Are joints flat and smooth? ▪ How far does the end gate of the paving unit overlap the previously placed lane ($^1/_2$ inch max)? If not, excess material should be raked off. ▪ Is excessive raking avoided? Minimal raking of the longitudinal joint should be done. ▪ Are longitudinal joints rolled from the hot side of the joint first? ▪ Are the joints straight and compacted? ▪ Ensure no gaps!
PROJECT INSPECTION RESPONSIBILITIES	
TRANSVERSE JOINTS	▪ Transverse joints should be avoided and should be used only at the end of paving or when problems occur in laying. ▪ Is the mat uniform up to the joint? ▪ Is excessive raking avoided when forming the joint? ▪ Is the joint compacted transversely? If there are restrictions, is the joint compacted longitudinally? ▪ Is the joint tight and well compacted and close to invisible?
BROOMING	▪ Does brooming occur shortly before placement of the bonded wearing course?
CLEAN UP	▪ Is all loose mix removed from the traveled way? ▪ Are any spills cleaned up?
OPENING THE MIX TO TRAFFIC	▪ The traffic travels slowly — 24 mph or less—over the fresh mat? ▪ Are reduced speed limit signs used? ▪ Are all construction related signs removed when opening to normal traffic?

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CHAPTER 12 INTERLAYERS

12.1 OVERVIEW

Pavement interlayers are materials or combinations of materials that can be placed within a pavement system during new construction, rehabilitation or preservation in conjunction with an overlay or surface treatment to extend pavement service life. Most interlayers will mitigate reflective cracking and reduce the amount of surface water that will penetrate into the pavement structure. Some interlayers will also allow for a reduction in thickness of the proposed overlay because interlayers can also provide stress and/or strain relief for the subsequent surface treatment.

By accomplishing these goals interlayers can help the new pavement surface last longer, provide a smoother ride throughout the life of the pavement by reducing cracking, and require less maintenance in the future. This will provide an overall more cost effective life cycle for pavement preservation, CApital Preventive Maintenance (CAP-M) or rehabilitation.

This chapter provides general guidelines on the use of interlayers. This informational guide on interlayers is not designed to be a standalone document in the decision making process. It should be noted that factors such as traffic volume, structural section and user delays should be taken into account when considering interlayers. There are many types of interlayers. The manufacturers of these materials have conducted research and have documentation on the various interlayers. It is recommended that manufacturer representatives be consulted if there are questions in using their products. See references at end of Chapter,

12.2 TYPES OF INTERLAYERS

Several types of interlayers have been used in California including chip seals and other manufactured products. Many of the types of manufactured products discussed in this chapter require a minimum 1.5- inch hot mix overlay to complete the application which places them outside the preservation category and within the CAP-M category for Caltrans. However, most City and County agencies in California allow up to 2-inch overlays for standard maintenance and can include these types of interlayers. All of the types of interlayers can also be used with deeper lift rehabilitation strategies. Some of the types of interlayers include:

Paving Fabric (Figure 12-1) **(**Formerly called Stress Absorbing Membrane Interlayer – Fabric (SAMI-F) - A non-woven geotextile fabric that is saturated with asphalt cement and placed with an asphalt concrete overlay (overlay) or chip seal. The paving fabric followed by a chip seal system has also been used as an interlayer application prior to an overlay, slurry seal, microsurfacing or second chip seal.

Paving Mat (Figure 12-2) - A non-woven fiberglass/polyester hybrid material that is saturated with asphalt cement and placed prior to an overlay.

Figure 12-1 Polypropylene Paving Fabric

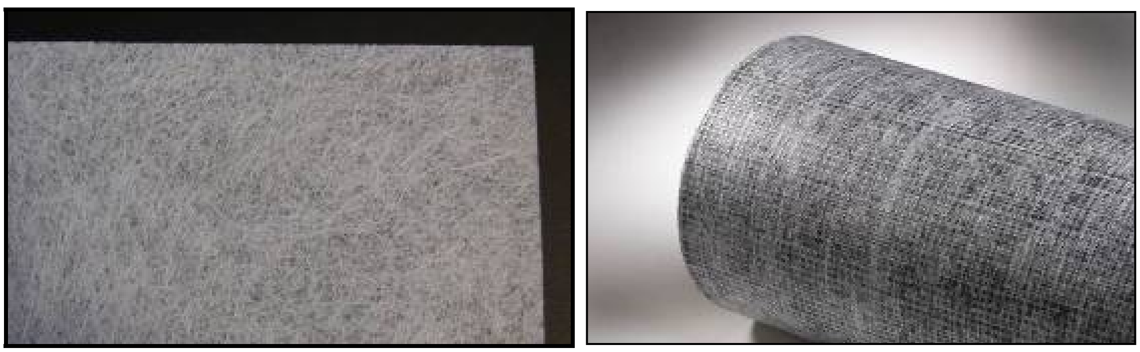
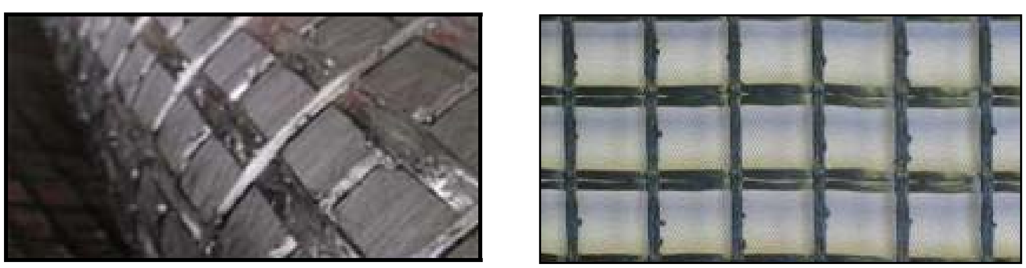


Figure 12-2 Fiberglass/Polyester Paving Mats

Paving Grids (Figure 12-3) – A material formed into a grid by a regular network of integrally connected elements with openings greater than or equal to 1/2 - inch to allow interlocking with the surrounding asphalt concrete materials. This material is applied either with a self-adhesive or with a lightweight scrim (a non-woven material <1.2 oz/yd2 attached to the grid) and/or tack application and is placed with an overlay.



Paving Grid with Scrim Backing Self Adhesive Paving Grid

Figure 12-3 Paving Grids

Paving Composite Grids (Figure 12-4) – A Paving Grid, as defined above, laminated, bonded or integrated with a paving fabric which is saturated with asphalt cement and placed with an overlay.

Composite Membranes (Figure 12-5). – Strips of various widths (12-inch, 18-inch, 24-inch, and 36-inch) comprised of rubberized and/or polymerized asphalt and geosynthetic materials that are applied either with a self-adhesive or asphalt tack application and placed prior to an overlay

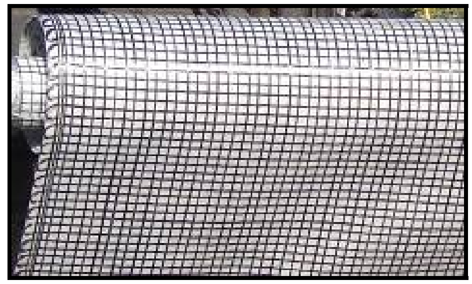



Figure 12-4 Paving Composite Grids with Polypropylene Backing


Figure 12-5 Application of Composite Membranes

Asphalt Rubber Chip Seal (AR Chip Seal) (Formerly called Stress Absorbing Membrane Interlayer – Rubber (SAMI-R)): Is an application of site blended, hot applied asphalt rubber covered with a pre-coated, pre-heated aggregate (Figure 12-6) placed prior to an overlay, slurry seal or microsurfacing. ARCS's are discussed in detail in Chapter 7 (Chip Seals).

Figure 12-6 Asphalt Rubber Chip Seals

Polymer Modified Asphalt Chip Seal (PMA Chip Seal) – A PMA Chip Seal (Figure 12-7) is an application of hot applied polymer modified asphalt (that may also contain crumb rubber) followed by an application of pre-coated, pre-heated aggregate. This application is placed prior to an overlay, slurry seal or microsurfacing. Details on construction and materials are discussed in Chapter 7 (Chip Seals).

Figure 12-7 Polymer Modified Asphalt (PMA) Chip Seal

Polymer Modified Rejuvenating Emulsion (PMRE Scrub Seal) – An application of a rejuvenating emulsion that is then "scrubbed" into the existing surface by use of a mechanized broom (Figure 12-8). A layer of crushed stone or sand is then applied prior to an overlay, slurry seal or microsurfacing. For more details, please refer to Chapter 6 (Fog and Rejuvenating Seals) and Chapter 7 (Chip Seals).

Figure 12-8 Scrub Seals

Microsurfacing, although not considered a traditional interlayer, has been effective as a pre-treatment or interlayer to fill ruts or act as a leveling course. This has been particularly effective on jointed concrete pavements. Microsurfacing has also been used to "lock down" brick and/or cobblestone surface movement prior to overlays. If rutting (not caused by structural or mix design issues) exists, microsurfacing can fill and level the ruts prior to an overlay thereby acting as an interlayer. Microsurfacing is designed to chemically set and stack the aggregate within the mix preventing or severely limiting post application compaction or continued rutting. Typical applications of microsurfacing are discussed in more detail in Chapter 9.

12.3 PROJECT SELECTION, INTERLAYER SELECTION AND BENEFITS

Once the decision is made to use an overlay or chip seal as a wearing surface, consideration should be given to whether using an interlayer is a cost-effective addition to the chosen strategy. Use of an interlayer is based on several factors including:

- Final surface treatment material and thickness (if overlay)
- Existing distresses - including types and severity levels.
- Climate and traffic conditions
- Moisture or water damage - which will accelerate the distresses, weakens the subgrade, and can cause premature failure of the new treatment.

- Costs of interlayer - which will vary greatly depending on the type of interlayer. Project design life or life extension benefits.

Interlayers may reduce the overall initial cost of a project by addressing the existing pavement distresses in lieu of digouts and repairs or thicker overlays. Interlayers may also decrease the life-cycle cost of a rehabilitation or maintenance treatment by significantly extending the life of the pavement. It is important to understand that most interlayers are not used to add structural strength to a pavement. However, some interlayers have established structural coefficients. Manufacturers' documentation should be consulted when considering an interlayer to add structural strength to a pavement section.

12.3.1 Project Selection Consideration

To make an informed choice on whether or not to use an interlayer the reader must be familiar with pavement distress types and should have a good understanding of Chapter 1 of this Guide. Tables 12-1 and 12-2 offer some guidance on the type of interlayers that have proven to be effective with different types and levels of distress in addition to cost considerations.

Interlayers were originally designed specifically to deal with cracking that is not load associated and caused by a lack of structureIf alligator cracking is associated with wheel loading and is combined with a lack of structure, then interlayers are not the optimum choice to satisfy this type of cracking. However, if alligator cracking exists across the entire surface of the roadway and is not specific to the wheel path/loading area, it is most likely caused by age oxidation of the pavement. Interlayers are an excellent choice to prevent this type of distress from reflecting through the new wearing surface.

Other types of distresses (rutting, bleeding, raveling, etc) are not normally addressed with the use of interlayers. In general, if active pumping is present, it usually indicates a poor base/subgrade condition which will require treatment prior to the use of an interlayer. If these distresses are addressed with a leveling course, or microsurfacing, then an interlayer could still be applied in conjunction with a surface treatment in order to gain life extension benefits.

12.3.2 Cover Requirements for Interlayer Materials

Table 12-1 summarizes the types of final wearing surface, with required depths for HMA, necessary to be used with each interlayer material. It should be noted that an overlay thickness greater than 1.2" is generally used for CAP-M or pavement rehabilitation rather than for pavement preservation. In order to be more inclusive all depths of paving and the most common interlayers are included here.[1]

[1] A CAP-M by Caltrans definition is Capitol Preventive Maintenance. A CAP-M treatment may still be a pavement preservation technique, but does not meet the "Maintenance" funding definition.

Table 12-1 Cover requirement minimums for various interlayer materials

Type of Interlayers	Chip Seal	HMA Overlay Thickness: Less than 1.2-inch	HMA Overlay Thickness: Min 1.5-inch	HMA Overlay Thickness: Min 2.0-inch	Slurry or Microsurfacing
Paving Fabric w/ Overlay			X		
Paving Fabric w/ Chip Seal	X	X			X
Paving Mat			X		
Paving Grid			X		
Paving Composite Grid				X	
Composite Strip Membranes			X		
AR Chip Seal		X			X
PMA Chip Seal		X			X
PMRE Scrub Seal		X			X
X = Acceptable Surface Treatment for Interlayer					

Fatigue/ Alligator Cracking

Alligator cracking is either load related or caused by age oxidation of the existing pavement. If alligator cracking is caused by associated wheel loading and is combined with a lack of structure, then either movement will exist in the pavement or it will be in the wheel path area only. Interlayers are not the optimum choice to satisfy this type of cracking. However, if alligator cracking exists across the entire surface of the roadway and is not specific to the wheel path/loading area, it is most likely caused by age oxidation of the pavement. Interlayers are an excellent choice to prevent age oxidation types of distress from reflecting through the new wearing surface.

Other types of cracking (thermal cracking, block, etc) are discussed in Chapter 1 and should be referred to and understood prior to moving on to Tables 12-2 and 12-3. Other types of distresses (rutting, bleeding, raveling, etc) are not normally addressed with the use of interlayers. If these distresses are addressed with a leveling course, or microsurfacing, then an interlayer could still be applied in conjunction with a surface treatment in order to gain life extension benefits.

Table 12-2 Anticipated Effectiveness vs. Types of Cracking and Moisture Intrusion

Interlayer	**Alligator Cracking** Load Related	**Alligator Cracking** Age Oxidation (Low to Medium)	**Alligator Cracking** Age Oxidation (Medium to High)	**Block, Longitudinal, and Non-Thermal Transverse Cracking** Low to Medium (CW <1/2 in)	**Block, Longitudinal, and Non-Thermal Transverse Cracking** High (12/ < CW < 1 inc)	**Thermal Cracking** Low (CW < ¼ in)	**Thermal Cracking** Medium (1/4 < CW < ½ in)	**Thermal Cracking** High (1/2 in or grater CW)	**Moisture Intrusion**
Paving Fabric w/ Overlay	N	E	G(1)	F	F(2)	G	F	N	E(3)
Paving Fabric with Chip Seal	N	E	G(1)	G	G(2)	F	N	N	E(3)
Paving Mat	N	E	E(1)	G	G(2)	E	G	N	E(3)
Paving Grid	N	E(1)	E(1)	E(1)	E(1)	E	E(1)	E(1)	N
Paving Composite Grid	N	E	E(1)	E	E(2)	E	E	E(2)	E(3)
Composite (Strip) Membranes	N	N	N	E	E	E	E	G	E
AR Chip Seal	N	E	E	E	G(2)	F	N	N	E
PMA Chip Seal	N	E	E	E	G(2)	F	N	N	E
PMRE Scrub Seal	N	E	E	E	E	G	F	N	E

(1) Interlayer with leveling course first
(2) Interlayer with crack filling first
(3) Interlayer dependent on binder application rate

E = Excellent
G = Good
F = Fair
N = Not Recommended

L = Low Severity
M = Medium Severity
H = High Severity
CW = Crack Width

The values in this table are informational based on available information.
This table will be updated as more data becomes available.

Table 12-3 Use vs. Climate and Traffic

Interlayer	Desert			Mountain			Coastal			Valley		
	< 5 M AADT	5 to 30M AADT	> 30M AADT	< 5 M AADT	5 to 30M AADT	> 30M AADT	< 5 M AADT	5 to 30M AADT	> 30M AADT	< 5 M AADT	5 to 30M AADT	> 30M AADT
Paving Fabric w/ Overlay	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Paving Fabric with Chip Seal	Y	N	N	Y	N	N	N	N	N	Y	N	N
Paving Mat	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Paving Grid	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Paving Composite Grid	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Composite (Strip) Membranes	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
AR Chip Seal	Y	Y	N	Y	Y	N	Y	Y	N	Y	Y	N
PMA Chip Seal	Y	Y	N	Y	Y	N	Y	Y	N	Y	Y	N
PMRE Scrub Seal	Y	Y	N	Y	Y	N	Y	Y	N	Y	Y	N

Y = Recommended N= Not Recommended

12.3.3 Moisture Intrusion

Damage caused by water intrusion into a pavement structural section is a major cause of many types of distresses including, but not limited to, loss of subgrade support, stripping (separation of the asphalt and aggregate in a hot mix material), potholes, localized failures, crack propagation, and pavement deterioration caused by freeze-thaw.

One of the major benefits of most interlayers is to provide a moisture barrier to surface water. The effectiveness of an interlayer moisture barrier is determined by the binder application rate associated with the respective interlayer system. This prevents the intrusion of the moisture into the pavement section and thereby degradation of the pavement from rain, landscape watering, etc. Water intrusion caused by underground issues such as springs or standing water in ditches cannot be addressed with an interlayer. Drainage work will be required prior to any installation.

12.3.4 Cost of Interlayers

The next factor associated with interlayer selection is cost. The installation of an interlayer will influence the initial cost of a project. Use of interlayer materials in lieu of digouts will typically decrease the overall cost of the project and provide a longer life for the new surface. Overall the life cycle cost of the pavement will have to be influenced positively in order to use an interlayer. Life extension data is provided in many of the references at the end of the Chapter.

Table 12-4 lists approximate costs for interlayers only. The costs are based on 2006 data. Cost of the surface treatment would have to be added to these costs for inclusion in any cost analysis.

Table 12-4 Approximate Costs of Interlayers Based on 2006 Data

Strategy	Size of Job	Installed Cost $/sq. yd
Paving Fabric for Overlay	Small Medium Large	1.50- 2.50 1.30- 2.00 1.10- 1.50
Paving Fabric for Chip Seal	Small Medium Large	1.90- 3.50 1.65- 2.75 1.40- 2.25
Paving Mat	Small Medium Large	2.75-3.50 2.30- 3.25 2.00-2.75
Paving Grid	Small Medium Large	8.00- 10.00 6.00- 8.50 5.00- 7.00
Paving Composite Grid	Small Medium Large	8.50- 10.50 6.50- 9.00 5.50- 7.50
Composite Strip Membranes (18" Width) per LF (Price is for material only)	Small Medium Large	1.20- 1.40 1.00- 1.20 0.80- 1.00
AR Chip Seal	Small Medium Large	4.25-5.00 4.00-4.75 3.75-4.55
PMA Chip Seal	Small Medium Large	3.50-5.00 3.00- 4.00 2.35-3.25
PMRE Scrub Seal	Small Medium Large	2.75-3.50 2.25–2.75 1.85-2.25

- Costs for the Surface Treatment are not included. These cost numbers are for interlayer installation only and include: mobilization, material (Asphalt and Interlayer), and installation.
- Definition of Job Sizes for Fabrics, Mat, Grids, and Composite Grids:
  - Small = ~5,000 SY per Day
  - Medium = 5,000 – 10,000 SY per Day
  - Large = 10,000 SY per Day or Greater
- Definition of Job Sizes for Composite Strip Membranes:
  - Small = ~1,000 LF per Day
  - Medium = ~3,000 LF per Day
  - Large = ~5,000 LF per Day
- Definition of Job Sizes for Chip Seal Applications:
  - Small = One of production
  - Medium = Two-Three days of production
  - Large = More than three days at same location

12.3.5 Life Extension of Interlayers

Interlayers can extend the life of a surface treatment when installed properly on the right pavement at the right time. The life extension benefit will depend on the following factors:

- Existing pavement condition, including any prep work done to the pavement
- Type of interlayer selected
- Proper installation/construction of the interlayer and
- Type and/or thickness of surface treatment selected

Therefore, one must consider all factors prior to selection of a specific interlayer. Other factors such as the environmental condition and traffic loading must also be considered. Manufacturer representatives may also be able to provide further guidance on proper usage of interlayers.

12.3.6 Examples for Selection of Most Appropriate Interlayers

The following examples and decision tree show how the factors and tables above should be used when considering the use of an interlayer. They are basic examples only to show how the tables and information presented in this chapter can be used to identify the most useful interlayers given the project's existing pavement distress, climate and traffic.

Example 1:
Problem: A structurally sound pavement has low to moderate alligator cracking due to age oxidation. Moisture intrusion is a concern. The traffic count is 5000 AADT. The final wearing surface will be a standard 1.2-inch maximum maintenance overlay. The climate is coastal. *Select most appropriate interlayer for use in this project.*

Solution: Based on the 1.2-inch maximum depth overlay, paving fabric, mat and composite grids would be ruled out due to a minimum 1.5-inch overlay requirement. (See Table 12-1). Due to the alligator distress, most of the remaining interlayers would do the job (Table 12-2). Composite Strip Membranes would be ruled out since they are typically only used on localized repairs in lieu of full width paving. This leaves Paving Fabric w Chip Seal, AR Chip Seal, PMA Chip Seal, and PMRE Scrub Seal. Due to the coastal climate, Paving Fabric w Chip Seal using a standard PME Emulsion, would probably be a concern during construction (See Chapter 7, *Chip Seals* for more information.) This leads to one of three options. AR Chip Seal, PMA Chip Seal or PMRE Scrub Seal. Strictly based on cost data, it would appear that the PMRE Scrub Seal would be the solution. However, other factors like life expectancy and climate may suggest a hot applied system instead.

Example 2:
Problem: An existing pavement with high severity block and transverse cracks (non-Thermal) is being considered for a 2.0- inch Capital Maintenance Overlay (CAP-M). Moisture intrusion is not an issue in this desert climate. The agency is concerned with reflective cracking occurring soon after the overlay is installed. The AADT is 40,000. *Select most appropriate interlayer for use in this project.*

Solution: Upon reviewing Table 12-2, the engineer can determine that Paving Fabric, Paving Fabric w Chip Seal, Paving Mat, AR Chip Seal and PMA Chip Seal are not the optimum materials for this project since they would not perform at the same level as the other products on this type of cracking. In addition, Composite Grid would not be a consideration because it would add cost for the moisture component which is not needed. This leaves Paving Grid, Composite Strip Membranes, or PMRE Scrub Seal. Upon considering the AADT in Table 12-3, the only two remaining options are Paving Grid and Strip Membranes. If the percentage of cracking is very high, then the Strip Membrane would be too cumbersome. This leaves the Paving Grid option as the best alternative.

Example 3:
Problem: A two-lane highway with isolated areas of moderate to high alligator cracking which is not load related, and low severity thermal cracking is being considered for an overlay of 1.5-inches. This is a mountainous climate that has high annual rainfall amounts. There are also 1/2-inch – 3/4- inch ruts in the wheel paths due to chain wear. The AADT is 20,000. *Select most appropriate interlayer for use in this project.*

Solution: The isolated alligatored areas should be repaired prior to any treatment application. The roadway would require either a Hot Mix leveling course or a microsurfacing placed as an interlayer prior to any final wearing course to address the ruts. Now the process of interlayer selection and evaluation can begin. The two concerns remaining are low severity thermal cracking and moisture. The AADT from Table 12-3 rules out Paving Fabric with Chip Seal. The moisture component rules out Paving Grids. The overlay thickness rules out Composite Grids. At this point all other interlayers are still a possibility. However according to Table 12-2 the AR Chip Seal and PMA Chip Seal are only listed as “F” instead of “G or E” for the thermal cracking. The better remaining choices are PMRE Scrub Seal, Paving Fabric, Paving Mat or Composite Strip Membranes. Upon reviewing the tables it is evident that with the exception of Composite Strip Membranes, all the products are “E” in one category and “G” in the other. This would lead to Composite Strip Membranes as the final choice. However, if the thermal cracking is too closely spaced one of the other materials might be a better compromise for the construction process. At this point the 3 remaining choices will have to be evaluated based on cost, material availability and construction limitations.

12.4 MATERIALS, APPLICATION AND SPECIFICATIONS

12.4.1 Paving Fabric

Paving fabric can be used with either hot mix overlays or with chip seals. If used with a hot mix overlay, the minimum depth of compacted overlay must be at least 1.5- inches which implies that it must be a CAP-M or Rehabilitation Strategy.

Table 12-5 lists specifications for paving fabric as per Caltrans Standard Specifications Section 88. Also see Section 92.104, “Applying Asphalt,” of Caltrans Standard Specifications for more details.

Table 12-5 Paving Fabric Specifications

Property	**Test Method**	**Value**
Elongation, minimum in each direction, %	ASTM D4632	50
Grab breaking load, 1-ich grip, mini8mum in each direction, lbs	ASTM D4632	100
Hydraulic bursting strength, minimum, psi	ASTM D3786	200
Mass, minimum, 0z/yd^2	ASTM D5261	4.1
Asphalt retention, minimum, gal/yd^2		0.2

Binder Requirements for Installation of Fabric prior to an Overlay - The surface area to receive the fabric shall be sprayed with a PG grade asphalt binder that is determined based on the ambient temperatures on the jobsite during installation. Higher ambient temperatures will require a stiffer binder in order to reduce the chance of bleeding under construction traffic. Typical binders used are PG 64-XX and PG 70-XX.

The typical binder application shall be 0.25±0.03 Gal/yd^2. In milled areas, binder application rate shall be increased by 0.05-0.10 Gal/ yd^2 to account for the increased surface area and voids. Good practice dictates that the asphalt binder be spread in the range of 290°F to 325°F as read on the temperature gauge on the truck applying the material.

Binder Requirements for Installation of Fabric prior to a Chip Seal – Either PG 64 – XX or PG 70 – XX binder shall be applied prior to installation of the paving fabric. The difference is in the application rate and the amount of saturation of the fabric required prior to the application of the chip seal. The typical application rate of the binder shall be increased to 0.30±0.03 Gal/ yd^2. In addition, the fabric shall be rolled to ensure that the fabric is completely saturated prior to the chip seal application.

12.4.2 Paving Mat

Paving mat is used under hot mix overlays of a minimum compacted thickness of 1.5-inches. This places paving mat in the CAP-M or Rehabilitation category. Specification requirements for paving mats are shown in Table 12-6.

Table 12-6 Paving Mat Specifications

Property	Test Method	Value
Ultimate Elongation, %	ASTM D5035	$\leq$ 5
Breaking Strength, lb/in^2	ASTM D5035	45
Mass per Unit Area, oz / yd^2	ASTM D5261	3.7
Melting Point, ^{o}F	ASTM D276	>400
Asphalt Retention, minimum, gal/yd^2	ASTM D6140	0.15

Binder Requirements for Installation of Paving Mat - The surface area to receive the mat shall be sprayed with a PG grade 64-XX or 70-XX. Higher ambient temperatures will require the stiffer PG 70 –XX binder to reduce the chances of oversaturation of the mat under construction traffic.

The typical binder application rate shall be in the range of 0.15 to 0.20±0.03 Gal/yd^2 depending on manufacturer. In milled areas, binder application rate shall be increased by .05-.10 Gal/yd^2 to account for the increased surface area and voids. Good practice dictates that the asphalt binder be spread in the range of 290°F to 325°F as read on the temperature gauge on the truck applying the material.

12.4.3 Paving Grid

Paving grid is used under hot mix overlays of a minimum compacted thickness of 1.5-inches. This places paving grid in the CAP-M or Rehabilitation category. Specifications for paving grids are shown in Table 12-7

Table 12-7 Paving Grid Specifications

Property	**Test Method**	**Value**		
		Grid Type		
		Class P1	Class P2	Class P3
Grid Aperture size, range, inches	Callipered	>0.5	>0.5	>0.5
Elongation, maximum, %	ASTM D6637	5	5	10
Mass, minimum, oz/yd^2	ASTM D5261	16	10	5.5
Tensile strength@ ultimate, minimum, lb/in		560 x 1,120	560 x 560	280 x 280

Binder Requirements for Scrim Applied Paving Grid - The surface area to receive the paving grid shall be sprayed with a PG grade 64-XX or 70-XX (depending on typical ambient temperatures on the jobsite) paving grade liquid asphalt binder. Higher ambient temperatures will require a stiffer PG 70 – XX binder in order to reduce the chances of oversaturation of the fabric under construction traffic.

The typical binder application shall be .06-.10 +/- 0.03 Gal/yd^2. Paving Grids shall not be placed directly on milled surfaces. Good practice dictates that the asphalt binder be spread in the range of 290°F to 325°F as read on the temperature gauge on the truck applying the material.

Binder Requirements for Self-Adhesive Paving Grid – Self-adhesive grids may require a tack coat for installation. Paving Grids shall not be placed directly on a milled surface. If a tack coat is specified and approved by the manufacturer or their representative, the tack coat shall be emulsified asphalt or PG grade binder as referenced above. If emulsified asphalt is used ensure a binder solids content of minimum 65% and a residual asphalt application rate of 0.02 – 0.05 gal/yd2. See the manufacturer's recommendations for details.

Cover Requirements for Paving Grid – An overlay thickness of minimum 1.5" compacted depth is required in conjunction with a paving grid application.

12.4.4 Paving Composite Grid

Paving composite grid is used under hot mix overlays of a minimum compacted thickness of 2.0-inches. This places paving composite grid in the CAP-M or Rehabilitation category. Specifications for paving composite grid are shown in Table 12-8.

Table 12-8 Paving Composite Grids Specification

Property	**Test Method**	**Value**		
		Grid Type		
		Class P1	Class P2	Class P3
Grid Aperture size, range, inches	Callipered	>0.5	>0.5	>0.5
Elongation, maximum, %	ASTM D6637	5	5	10
Mass, minimum, oz/yd^2	ASTM D5261	16	10	5.5
Tensile strength@ ultimate, minimum, lb/in		560 x 1,120	560 x 560	280 x 280
Fabric Requirements				
Grab Tensile Elongation, maximum in each direction, %	ASTM D4632	50		
Grab Breaking Load, 1-inch grip, minimum in each direction, lbs	ASTM D4632	90		
Hydraulic Bursting Strength, minimum, psi	ASTM D3786	180		
Mass, minimum, oz/yd^2	ASTM D5261	3.6		

Asphalt Retention, minimum, gal/yd^2		0.2

Binder Requirements for Paving Composite Grid Installation - The surface area to receive the composite grid shall be sprayed with a PG grade 64-XX or 70-XX (depending on typical ambient temperatures on the jobsite) paving grade liquid asphalt binder. Higher ambient temperatures will require a stiffer PG 70 – XX binder in order to reduce the chances of oversaturation of the composite under construction traffic.

The typical binder application shall be 0.25±0.03 Gal/yd^2. In milled areas, binder application rate shall be increased by .05-.10 GSY to account for the increased surface area and voids. Good practice dictates that the asphalt binder be spread in the range of 290°F to 325°F as read on the temperature gauge on the truck applying the material.

12.4.5 Composite Strip Membranes

Composite strip membranes are used under hot mix overlays of a minimum compacted thickness of 1.5-inches. This places composite strip membranes in the CAP-M or Rehabilitation category. The specifications for the materials used in composite strip membranes are shown in Table 12-9.

Table 12-9 Composite Strip Membranes Specification

Property	Test Method	Value
Thickness, mills	ASTM D5147	65
Grab Tensile Strength, lbs	ASTM D4632	200
Grab Tensile Elongation, %	ASTM D4632	40
Puncture Strength, lbs	ASTM D4833	200
Permeance, perm, maximum	ASTM E96, Method B	0.1
Strip Tensile, lbs/in	ASTM 882, Modified	50
Pliability	¼ inch Mandrel, 180 @ -25^{o}F	No cracks

Primer Placement-The purpose of a primer is to improve adhesion of the strip membrane under "marginal" conditions that tend to reduce bonding. Such conditions include moisture, dust, cold temperatures and irregular surfaces. Use only primers recommended by the manufacturers of the products.

12.4.6 Asphalt Rubber Chip Seals (ARCS)

Asphalt rubber chip seals can be used under hot mix overlays of any thickness or slurry or microsurfacing. This allows ARCS to be used for maintenance, CAP-M or Rehabilitation.

Asphalt rubber chip seals (ARCS) have a long history of being used as interlayers prior to placement of an asphalt concrete overlay. They are similar in application to a conventional type chip seal, but the application rate of the binder is much higher ranging from 0.55-0.65 gal/yd^2. The thicker layer of binder provides improved resistance to reflection cracking.

The material requirements for the asphalt rubber binder component of the system are detailed in Chapter 7 of this manual. More information on the use of this product can be found in the Caltrans Asphalt Rubber Usage Guide updated in 2006.

12.4.7 PMA Chip Seals

PMA chip seals can be used under hot mix overlays of any thickness or slurry or microsurfacing. This allows PMA Chip Seals to be used for maintenance, CAP-M or Rehabilitation.

Polymer modified asphalts are currently being used in chip seal applications and also can be used as interlayers prior to the application of an HMA overlay or slurry seal or microsurfacing. Polymer Modified Asphalt materials are created at asphalt terminals. These materials are sprayed at lower temperatures than the ARCS and do not require any specialized environmental controls.

The application rates for these hot applied binders are typically 0.35-0.50 Gal/yd^2. These materials can also incorporate up to 10% ground tire rubber. The use of PMA for chip seals is discussed in more detail in Chapter 7 of this Guide.

12.4.8 PMRE Scrub Seals

PMRE scrub seals are used under hot mix overlays, slurry seals or microsurfacing. This places PMRE Scrub Seals in the maintenance, CAP-M or Rehabilitation category.

PMRE Scrub Seals are currently being used by many agencies in lieu of extensive crack sealing prior to a different application. Due to the nature of the process, cracks are filled with the emulsion during the construction of the seal. Emulsion application rates are similar to that of standard chip seal emulsions, but the “scrubbing” process places additional material in the cracks to seal them.

Scrub seals are discussed more fully in Chapters 6 and 7 of this guide.

12.5 CONSTRUCTION GUIDELINES

The following are general guidelines to ensure a successful installation of material interlayers (paving fabric, paving mat, paving grid, paving composite grid and composite strip membranes). For each specific project, the project specifications, project engineer’s direction, and manufacturer’s recommendations must be followed. Construction guidelines for chip seals can be found in Chapter 7.

12.5.1 Surface Preparation

- Potholes, cracks greater than 1/4- inch, and/or local distresses related to structural or subgrade failures shall be repaired.
- Pavement must be free of dirt, water, oil, and other foreign materials. Broom or air-clean the surface if necessary. This is an extremely important step. Spraying asphalt onto contaminants will prevent interlayers from adhering to the existing pavement surface. If the interlayer is not properly adhered to the existing pavement surface, the materials may delaminate during or after construction.
- Rutting must be corrected through milling or by placing a leveling course prior to placement of an interlayer.
- If a finish or profile milling is performed, a leveling course is not required prior to placement of most material interlayers. This will depend on the smoothness of the surface created during the milling operation and the specific interlayer material being placed. The following finish tolerances are required for profile or finish milling:
    - Remove asphalt concrete a minimum depth of 1/4 - inch
    - Provide a surface relief (distance between ridges) of no more than 1/4 - inch

  - Maintain 1/4 - inch grade tolerance over (transversely and longitudinally)
  - There shall be no more than 1/4 - inch vertical height variation between planed and un-planed surface at inside edge of conform and taper mills
- If cold planing is performed, a leveling course is typically required prior to placement of material interlayers other than paving fabric. This will depend on the smoothness of the surface created during the milling operation. The following finish tolerances are required for placement of paving fabric over a cold planed surface
  - Remove asphalt concrete a minimum depth of 3/8 - inch
  - Provide a surface relief (distance between ridges) of no more than 3/8 - inch
  - Maintain a 3/8 - inch grade tolerance over (transversely and longitudinally) from a 10 foot straightedge
  - There shall be no more than 3/8 - inch vertical height variation between planed and unplaned surface on inside edge of conform and taper mills
- With the exception of using composite strip membranes, a leveling course is required over all Portland cement concrete pavements. Typical Caltrans practice for rigid pavements is to crack and seat prior to a rehabilitation overlay using interlayer. However, interlayers can be used on non crack and seat rigid pavements prior to overlays also.
- All paving grid applications, except for paving composite grids, require a leveling course.
- Grade and cross-slope have been established.
- Manholes, catch basins, and utility appurtenances have been raised to a level of the new overlay.

12.5.2 Road Surface Condition (Before Installation)

- The pavement must be moisture free. Do not install material interlayers during precipitation
- The ambient air temperature must be $\geq 50^{o}$F and rising
- Pavement temperature must be $\geq 40^{o}$F and rising
- On newly placed asphalt surfaces, the surface temperature must be allowed to cool below 130ºF before placement. If necessary, the leveling course may be opened to traffic prior to placement of the interlayer to allow the tires to further knit the surface.

12.5.3 Binder Materials and Application

Binder materials must meet the following requirements.
- Delivered from an approved source.
- Delivery ticket specifies grade for use on the project.
- Temperature is within the specified range

Apply binder uniformly over the clean surface using a distributor truck with a current calibration. The truck shall have clean, uniformly angled, properly sized nozzles and a bar that is at the correct height to apply the material in a triple overlap spray pattern (Figure 12-9). Edge nozzles shall be clog free and angled perpendicular to the spray bar for a clean edge.

Figure 12-9 Interlayer Binder Application

For Paving Fabric, Mat, and Composite Grid, a binder application of PG Graded Asphalt (PG 64 – XX or PG 70 – XX) shall be used to saturate and/or bond the interlayer material to the existing pavement. PG 70 – XX or higher is recommended for job sites that are exposed to high ambient temperatures during the calendar year. For Paving Grid, refer to manufacturer's recommendations.

The distributor truck applying the asphalt binder shall be equipped with computer control and readout to ensure proper application rates. Spot application rate checks should be performed as per Section 12.6 of this chapter.

12.5.4 Material Application General Guidelines

- Using mechanical placement equipment, or manually, embed the interlayer in the hot PG tack coat before the asphalt cools. (Figures 12-10. 12-11, 12-12 and 12-13). If using an emulsion for placement of a paving grid, allow the tack to break completely before placing the grid
- Keep the interlayer material taut and wrinkle free. Providing tension during application will help to achieve this. Providing broom pressure will also assist in reducing wrinkles
- For sharp curves, material can be cut from the roll to desired length and positioned by hand to avoid wrinkles
- For paving fabric and mat, transverse overlaps shall be 4 to 6 inches. Longitudinal overlaps shall be 2 to 4 inches
- For paving grid and composite grid, transverse overlaps shall be 3 to 6 inches. Longitudinal overlaps shall be 1 to 2 inches
- Transverse overlaps should be lapped in the direction of paving to minimize the risk of being picked up by the paving equipment and process. All overlaps shall receive an application of tack coat.
- Only construction and emergency vehicles are allowed to drive on the interlayer prior to the placement of an overlay
- Longitudinal joints shall be placed on lane delineation if possible.
- Manufacturers' MSDS's shall be reviewed and adhered to during installation

Figure 12-10 Tractor Mount Application of Fabric

Figure 12-11 Truck Mount Application of Paving Mat

Figure 12-12 Tractor Mount Paving Grid Installation

Figure 12-13 Composite Paving Grid Installation

12.5.5 Specific Guideline for Each Type of Interlayers

The following items are specific to each of the individual interlayer materials and need to be adhered to in addition to the general guidelines above. Manufacturer guidelines and recommendations should be consulted prior to installation.

Specifics for Paving Fabric Installation prior to HMA Overlay

- Large wrinkles (1- inch and larger) shall be slit and lapped in the direction of paving
- All fabric shall be broomed in order to maximize pavement contact and remove air bubbles
- The width of liquid asphalt application shall be 2 to 4 inches beyond the edges of the fabric
- No joints shall be lapped with more than two layers of fabric

Specifics for Paving Fabric Installation prior to Chip Seal Application

- The width of liquid asphalt application shall be 2 to 4 inches beyond the edges of the fabric
- All wrinkles must be cut out completely with no lapping. Wrinkles and/or laps will reflect through a chip seal immediately
- Fabric shall be butted at both longitudinal and transverse joints
- Fabric must be completely saturated during lay down procedure. Binder application rate for the chip seal can be increased to compensate for incomplete saturation of the fabric, however this is not the recommended practice.
- Fabric shall be rolled immediately after placement to maximize pavement contact and remove air bubbles.
- Sanding can be used to prevent roller tires from adhering to and picking up the fabric. The cover sand shall be uniform, clean dry and free from deleterious matter. All loose sand shall be removed prior to application of the chip seal
- Ambient temperature requirements for fabric under chip are between 60°F and 100°F. Pavement temperature shall be 55°F and rising. Fabric shall not be placed unless temperatures and weather conditions will also allow for completion of the chip seal immediately following the fabric application
- Brooms on lay down equipment shall apply uniform pressure across full width of fabric
- Grades or slopes greater than 10% require additional consideration
- Fabric for chip applications are not recommended in the following areas
    1. The bubble portion of cul-de-sacs
    2. Sharp curves
    3. Intersection radii
    4. The last 100 feet approaching an intersection that requires traffic to stop, turn or reduce speed

Specifics for Paving Mat Installation prior to HMA Overlay

- If milling of the existing asphalt pavement has been performed, a leveling course may be required prior to placement of a paving mat. This will depend on the smoothness of surface created during the milling operation
- A leveling course is required over all Portland cement concrete pavements
- The width of liquid asphalt application shall be 2 to 4 inches beyond all edges of the mat
- Large wrinkles (1-inch and larger) shall be slit and lapped in the direction of paving

Specifics for Paving Grid Installation prior to HMA Overlay

- A leveling course is required for all Paving Grid Installations
- For scrim-applied paving grids, tack coat shall be applied at a rate between 0.06 and 0.10 gal/yd^2 that will bond the scrim and the paving grid to the existing pavement
- For self-adhesive paving grids, if a tack coat is specified and approved by the manufacturer or their representative, then the tack coat shall be used on the self adhesive paving grid. See manufacturer's recommendations for details
- Prior to installation of a self adhesive grid, test for proper adhesion to the existing pavement according to manufacturer's adhesion guidelines

Specifics for Paving Composite Grid Installation prior to HMA Overlay

- If milling has been performed, a leveling course is recommended prior to placement of composite paving grid, especially if the milling is deep or rough
- A leveling course is highly recommended over all Portland cement concrete pavements

Basics for Asphalt Rubber Chip Seal Construction (Figure 12-14) *The specifics listed here are very limited. For complete documentation on Chip Seal Construction refer to Chapter 7 of this manual.*

- Asphalt rubber chip seal applications are similar to those of a conventional chip seal
- The surface must be prepared and cleaned
- The binder is applied at an application rate which is a factor of the existing distresses, traffic and size of cover aggregate but is typically between 0.55-0.65 Gal/yd^2.
- Aggregate is typically pre-heated and pre-coated to reduce the amount of dust on the aggregate and ensure a good bond to the sprayed asphalt
- The aggregate is applied as soon as possible and rolled into the mat
- Finishing consists of brooming off the excess aggregate

Figure 12-14 Asphalt Rubber Binder Being Applied

Basics for Modified Binder Chip Seal Construction (Figures 12-15 and 12-16).*The specifics listed here are very limited. For complete documentation on Chip Seal Construction refer to Chapter 7 of this manual.*

- PMA chip seal applications are similar to those of a conventional chip seal also
- The surface must be prepared and cleaned
- The binder is applied at an application rate which is a factor of the existing distresses, traffic and size of cover aggregate but is typically between 0.35-0.50 gal/yd^2.
- Aggregate is typically pre-heated and pre-coated to reduce the amount of dust on the aggregate and ensure a good bond to the sprayed asphalt The aggregate is applied as soon as possible and rolled into the mat
- Finishing consists of brooming off the excess aggregate
-

Figure 12-15 Installation of Binder

Figure 12-16 Chips Applied and Sweeping Edge for 2nd Pass

Basics for Scrub Seal Construction(Figures 12-17 through 12-19).*The specifics listed here are very limited. For complete documentation on Chip Seal Construction refer to Chapter 7 of this manual.*

- Scrub seal applications are similar to those of a conventional chip seal
- The surface must be prepared and cleaned
- The binder is applied at an application rate which is a factor of the existing distresses, traffic and size of cover aggregate but is typically between 0.25-0.40 Gal/yd^2.
- The binder is then "scrubbed" into the existing pavement.
- Aggregate is then applied and rolled. Due to the nature of rejuvenating emulsions the aggregate does not have to be as clean as conventional chip seal aggregates. It also does not require pre-heating or pre-coating.

Figure 12-17, 18, 19 Scrub Seal Construction

12.6 FIELD TESTING FOR MATERIAL INTERLAYERS

The following focuses on paving material type interlayers only. (Paving Fabric, Mat, and Composite Grid). **Field testing related to chip seals may be found in Chapter 7 of this Guide**.

12.6.1 Equipment Required

- Field Inspection Form
- Weight to application rate conversion chart (Table 12-10)

Table 12-10 Weight to Application Rate Conversion Chart

g/ft^2	oz/ft^2	gal/yd^2
82	2.88	0.19
90	3.18	0.21
99	3.48	0.23
107*	**3.78**	**0.25**
116	4.09	0.27
124	4.39	0.29
133	4.69	0.31
141**	**4.99**	**0.33**
150	5.29	0.35
158	5.59	0.37
167	5.89	0.39
* Typical Overlay Application		
** Typical Chip Seal Application		

- Measuring Scale of 2 g accuracy (preferably portable)
- Testing units (12” X 12” rigid material, 1/8th or ¼ inch hardboard or plywood)

12.6.2 Testing Activities Required for Tack Coat Application Rate Determination

- Pre weigh test units and write weight on underside of test units.
- Have Binder Spreader unit pull to level area (both across and down the length of the truck).
- Record starting gallons of asphalt binder taken from Spreader Truck tank gauge. Truck must be parked level for 1st and all subsequent readings. Using the same location is optimal
- Instruct the spreader operator not to pump additional binder onto or off the truck without taking readings.
- Record the temperature of the asphalt binder inside the tank.

12.6.3 Calibration

- Have binder application spray unit locate at starting point of tack coat placement.
- Instruct spreader operator to set the application rate of the spreader to the desired rate (e.g. 0.25 Gal/ yd^2).
- Place test unit(s) on pavement (minimum of one, maximum of three) directly in front of truck. If one, place in center of truck, if three place in center of truck and outside of wheel paths.
- Instruct the operator to proceed forward applying asphalt binder until the test unit(s) has been crossed with sprayed asphalt binder.

- Retrieve test units (show care handling hot asphalt coating) and re weigh.
- Subtract the original weight recorded on the underside of the sample from the gross weight including the sprayed asphalt binder.
- Compare resulting weight with binder weight application chart.
- If required, have operator adjust application rate up or down to reach desired rate.
- Retest if necessary until desired application rate is confirmed. (Note: the same testing units can be used repeatedly by simply recording new tare weights prior to a second application of binder).

12.6.4 Project Monitoring

- All rolls of paving interlayer materials should arrive at the job site in a plastic wrapper. This indicates the roll is complete and has been protected from sun and water. (If partial rolls are brought to the jobsite, these should be set aside and all placed at the same time as the length will have to be calculated to determine total square yardage). On partial rolls, the inspector can request one or two wraps of the exposed fabric to be removed to assure no ultraviolet degradation has occurred. The manufacturers tag each roll both outside on that wrapper as well as inside on the cardboard core. These tags provide all necessary information regarding the manufacturer, manufacturer tracking number, the weight per square yard, the width and length of that roll.
- If the inspector is not with the interlayer laydown operations at all times the spreader operator shall retain the tags as the rolls are applied, for determination of total square yards placed.
- At any time during the project the inspector can take another reading on the tank (truck must be level) at the completion of a full fabric roll.
- Subtract the current tank reading from the beginning to determine total gallons of paving grade asphalt binder placed.
- Retrieve the roll tags from the spreader operator to determine number of rolls installed.
- Multiply the number of rolls times the square yards in the roll to get total square yardage.
- Divide the total gallons of paving grade asphalt binder placed by the total square yards placed and determine tack coat application rate to that point.

12.7 TROUBLESHOOTING GUIDE

The following guide provides a summary of possible problems, typical causes and potential solutions associated with paving material interlayers (Table 12-11). The guide was primarily based on guidelines from the FHWA Pavement Preservation Checklist Series and manufacturers' installation guidelines. The troubleshooting guide for chip seals used as interlayers may be found in Chapters 6 and 7.

Table 12-1 Troubleshooting Guide for Interlayers

Problem	Causes and solutions
Wrinkles have formed during placement of a material interlayer	Cause: • Lay down equipment out of alignment or lack of tension on roll • Lay down equipment turned without stopping and cutting the interlayer • Equipment has turned on top of the interlayer • Broken or weak core causes sagging Solutions: • Make sure fabric applicator is driving straight; veering to the left or right can cause wrinkles • Check equipment for proper tension and alignment of the fabric roll • Minimize equipment traffic on interlayer • Insert metal bar inside fabric core to prevent fabric rolls from sagging
Vehicles and/or equipment tires are picking up, sticking to or tearing material interlayer	Cause: • High ambient temperatures • Over-application of binder (if this is the cause, reduce binder rate but do not go below the specified application rate) • Excess construction or public traffic on installed material Solution: • Broadcast hot mix asphalt or sand over interlayer (sweep up all sand prior to surface treatment) • Do NOT reduce tack coat below specified application rate • If problem is persistent in an area, switch to a modified asphalt tack coat • Repair damaged areas
Blisters form under material interlayer	Causes: • Pavement is wet and/or saturated Solution: • Roll the interlayer with a rubber-tire roller until it adheres to the pavement • Dry the rest of the pavement before continuing with interlayer installation • Install drainage if subgrade is saturated and not drying out
Paving fabric shrinks (edge curls) when laid on tack coat	• Cause: • Tack coat is too hot • Solution: • Cool tack coat before applying or wait longer before installing fabric or mat on tack coat
Material interlayer is not	Cause:

Problem	Causes and solutions
sticking to pavement	• Binder too cold • Insufficient Binder • Milled surface too rough • Material placed with wrong side down • Binder absorbed by leveling course or patch Solution: • Check binder temperature and application rate • Close gap between distributor and tractor • Add leveling course or patching • Ensure proper material placement
Binder not sticking to pavement	Cause: • Pavement is wet or dirty (dust/oil/etc) • Binder too cold Solution: • Clean and or dry the pavement • Check and adjust binder temperature

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CHAPTER 13 IN-PLACE RECYCLING

13.1 OVERVIEW

This chapter covers in-place recycling as an alternative maintenance option for hot mix asphalt (HMA) pavements. The specific goal of this chapter is to provide information on the materials, design, and construction of cold in-place recycling (CIR) and hot in-place recycling (HIR). The major topics include:

- Materials
- Mix Design
- Construction
- Quality Control
- Troubleshooting

Although this chapter focuses on CIR and HIR, it is recognized that there are other alternatives to recycling pavement materials. For example, HMA and other materials such as chip seals and previous overlays might be removed from the existing pavement surface by milling and then used elsewhere such as an addition to HMA at a central plant. Although this is a good and ongoing practice, it is not the subject of this chapter on surface recycling. In addition, other materials such as crushed portland cement concrete may be returned to the same project and laid down in the same manner as for the CIR process.

Because of the success of surface recycling, it has become increasingly a choice for maintenance rather than just for rehabilitation or reconstruction. The functional performance of pavements can be improved, since the top few inches are reworked and can correct such deficiencies as rutting, raveling, and surface cracking, thus improving the ride quality as well as structural integrity. Surface recycling is not recommended when the underlying pavement layers are structurally deficient.

This chapter is limited to the broader features of in-place recycling in order to provide a general understanding of the concept, with enough detail so that the reader may gain a good feel for the concept along with the steps required to achieve a successful project. Additional more detailed information may be found in the references.

13.1.1 Cold In-Place Recycling

The CIR process removes a portion of an existing asphalt pavement by milling, and then replaces it with reworked asphalt mix with additives. Typically, the steps include:

- Milling the existing asphalt layers to some partial depth
- Typical depth is 3 inches, but ranges from 50 to 100 mm (2 to 4 inches)

- Size the reclaimed material, mix with additives, and repave
- If needed, add virgin material before relaying the recycled mix

As the name implies, CIR is accomplished without heating any of the components, before or after placement. Depending upon the structural requirements of the overall pavement and its intended use, the CIR typically receives a wear course such as a chip seal or HMA overlay. Note that CIR is contrasted to full depth reclamation (FDR), which often incorporates the entire pavement section and may incorporate a substantial amount of underlying base material, for example. Also note that a CIR pavement will require time to dry (aerate) the free moisture from the mix as well as cure the asphalt emulsion before final compaction and placement of a wearing course on top.

CIR is often used on low traffic volume roads or secondary roads where a central hot mix plant may not be convenient for obtaining new HMA for an overlay (FHWA 2003). It can also be used on high volume roadways as a repair to the existing pavement and a mitigation layer for cracking in conjunction with a HMA overlay. This process is effective in restoring or improving the cross section profile, crown, cross slope drainage, as well as removing cracked pavement (Khandall and Mallick, 1997). Success will depend on careful evaluation of the existing pavement to determine the cause of distress and recognize the limits of CIR, and that it will not restore a deficient subgrade, for example.

13.1.2 Hot In-Place Recycling

The HIR process is not unlike CIR, except that heat is used to soften the existing asphalt surface. The softened asphalt surface is mechanically loosened, mixed as necessary with recycling agent, aggregate, or additional HMA, and then re-laid, without removing it from the pavement site (Button, et al 1994). HIR is effective at correcting surface distress that is limited to the top 25 to 50 mm (1 to 2 inches) but depending on the process and extent of cracking, may extend to 3 inches. The process is effective for correcting minor surface rutting, corrugations, raveling, flushing, loss of surface friction, minor thermal cracking, and minor load associated cracking (Button, et al, 1994). Note that HIR should be used only if the underlying pavement layers are structurally sound.

The HIR process can be performed as either a single-pass operation that combines the restored pavement surface material with virgin material, or as a two-pass operation, in which the restored pavement surface material is re-compacted and the application of a new wearing surface follows at a later time. Three different processes are commonly used in HIR, including:

- Surface recycling, including heater-scarification
- Repaving and remixing
- Remixing

These are described in some detail under the section on Construction.

13.2 MATERIALS

13.2.1 Project and Materials Selection

In Chapter 3 there is a detailed description and discussion of how a project is selected for maintenance or rehabilitation. It is important that all the available data and resources are utilized to determine the most appropriate method for a given project. Figure 13-1 is a summary of the process (Epps, et al 1980) and incorporates the existing pavement condition, including tests to help with the cause analysis, the past history of this project as well as other projects that might have used the same materials in the vicinity, thus could experience the same problems.

A key part of this process shown in Figure 13-1 is the sampling and evaluation of materials used in the asphalt pavement that needs rehabilitation. For the more detailed evaluation of the recycling option, this chapter addresses the surface recycling, either hot or cold. For both CIR and HIR, the proper selection of materials is dependent on a thorough evaluation of the existing in-place materials. It is important to identify the characteristics of the existing pavement materials so that the correct types and amounts of additives can be determined (i.e., recycling agents and/or binders) and the need for additional materials such as virgin aggregate can be ascertained (FHWA, 2001, Kendalh, et al, 1997). A more thorough treatment of this subject can be found in Ref. 2.

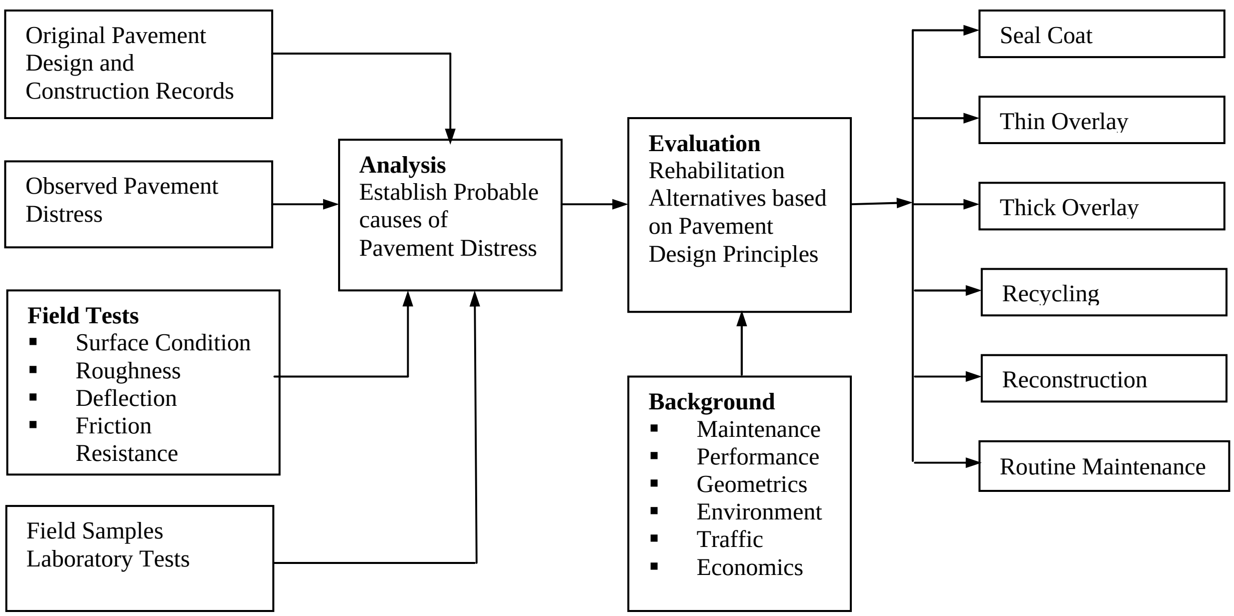

Figure 13-1 Summary of process to arrive at the best option for pavement rehabilitation (Epps, et al, 1997)

13.2.2 CIR Materials

A thorough understanding of all the materials that make up a CIR project is important to its success. Of primary concern is the existing asphalt pavement and its condition, and when it is removed from the surface, and then becomes reclaimed asphalt pavement (RAP). Other materials will then be added in order to make up the desired combination that will serve its intended use. These materials will include added aggregate, new HMA if any is needed, and asphalt additives.

Reclaimed Asphalt Pavement (RAP)

RAP is the milled asphalt pavement that is removed from its original position or depth of layers in the pavement, and will be used for the CIR mixture. Samples of RAP are obtained from core samples obtained during the preliminary stages of project evaluation. The properties of the RAP are determined by detailed laboratory testing, but the core samples will also be used to evaluate the uniformity of the RAP along the project roadway, and note any changes that may have resulted from past designs and maintenance that may have occurred at different times. In addition, the depth of the pavement to be recycled is critical for successful field construction, so that unexpected problems can be avoided. For example, if the planned depth of CIR is 3 in, and the existing pavement depth varies from 2 ½ in to 5 in thick, a large portion of the underlying material would be incorporated into the mixture and cause variability of the recycled mixture. Good records of the core samples should include any visual observations, photographs, and trimming the samples to the depth to be recycled, and then testing of the material for the design of the final CIR pavement mixture. Typical testing should include at least the following:

- aggregate gradation of the RAP
- large projects may warrant additional testing and evaluation as follows:
  - Moisture content if samples are obtained using dry coring or cutting
  - Asphalt binder content
  - Dry and retained strength of the recycled mixture for moisture sensitivity evaluation
  - Raveling potential of the recycled mixture based on observation of the original pavement

The above information will be used as the starting point to determine what additives or other materials will be required to design a mixture with the desired characteristics for the newly recycled pavement. For example the primary concern may be to correct an existing mix deficiency such as flushing, or to generally upgrade the material to meet new standards. The mix design should follow Caltrans Lab. Procedure # 8, METHOD OF TEST FOR DETERMINING THE PERCENT OF EMULSIFIED RECYCLING AGENT TO USE FOR COLD RECYCLING OF ASPHALT CONCRETE. This method is available at: www.dot.ca.gov/hq/esc/Translab/fpmlab.htm.

New Aggregate

Although not often added, some projects may require the addition of virgin aggregate in order to reduce the average binder content because of flushing, for example. Or, there may be a desire to improve the strength or thickness of the recycled layer. The new aggregate may be from the same or different source as the original pavement, but will need to meet all material specifications including quality, and especially gradation in order to complement that in the RAP to meet the final gradation of the combined materials (ARRA 2001). An alternative to new aggregate might be RAP from another project that has been sized to meet the needs of the project at a nearby central plant.

Recycling Additives for CIR

There are myriad material options for additives to improve the properties of the CIR pavement. The option selected may be determined in the laboratory by making trial mixtures using different additives for comparison. The goal is to change or improve the quality of the binder in the RAP, but also may be for aiding compaction. Because the CIR is mixed at ambient temperatures, the choices must be compatible with this limitation, but the opportunity is good for utilizing a material(s) that will work well. A summary of these options is shown below (FHWA 2001, ARRA 2001).

Asphalt Emulsions

The most common binder for CIR is asphalt emulsion, available in several types and grades. Those that have found success in CIR include medium and slow setting, both cationic and anionic types, as well as anionic high-float emulsions. However, the use of medium set and high float emulsions in California are limited due to environmental concerns. Some may be combined with other modifiers such as polymers to improve properties of the mixture.

Recycling Agents

For CIR, recycling or rejuvenating agents are usually combined with an asphalt emulsion. These combinations are typically custom blended by the suppliers, usually to fit a particular material (RAP) and also the location, because of climatic concerns. The idea is to simultaneously restore desirable asphalt binder properties and at the same time add more binder for improving the mixture or to make up the difference when new aggregate is added. A cautionary note is that either the portion of new binder or recycling agent may not be appropriate for the particular RAP if used simultaneously resulting, for example, in too soft a binder or too much binder, without the ability to make changes on the run.

Cutback Asphalts

Caltrans no longer specifies cutback asphalt for several reasons. In past years, in the 1930s, cutback asphalts were the binder of choice for cold in-place recycling because they were stable and readily mixed with a wide range of aggregates and RAP. But they are now on the way out because of environmental concerns of release of hydrocarbons into the atmosphere; many government agencies no longer allow their use. There is also safety concern because of their low flash point, and the potential for causing fires on the jobsite.

Foamed Asphalts

An alternative method of adding asphalt binder to CIR mixtures is by foaming the asphalt to provide a means of coating the RAP and aggregate. This system requires a means of injecting hot asphalt cement (not asphalt emulsion or cutback) and water together in a chamber to produce a foaming action. The expansion of the foam results in a condition that allows it to disperse, wet, and coat the RAP-aggregate materials with asphalt. Because the asphalt cement, which is paving grade and is not liquid at ambient temperature, quickly reverts to its semi-solid state, the binder tends to cement particles together rather than coat them. As such it is not particularly suited to rejuvenating or restoring asphalt binder properties, particularly the fine fraction.

Chemical Additives

There are several types of mineral or chemical additives that have proven beneficial to the construction and performance of CIR materials and pavements. Liquid anti-strip additives are an effective material in reducing water sensitivity. Dry materials, such as fly ash, portland cement, and lime have all been used, typically in a slurry form to reduce dust, for use in providing early setting and curing of asphalt emulsions, as well as early strength gain to overcome the effects of wet weather and/or the need to overlay the CIR pavement earlier than would normally be practical. The idea is that the cement, for example, absorbs the water contained in the asphalt emulsion, resulting in quicker setting and faster breaking and curing. Using this approach can also reduce the tendency for early rutting during the cure period, especially for poorly graded or rounded aggregate mixtures.

13.2.3 HIR Materials

In a manner similar to that for CIR, each project must be evaluated to determine the specific properties of the in-place pavement condition and RAP and any other materials anticipated to be used in the final recycled mixture. Determination of the mechanisms that caused the distress will be important to solving the problem and preventing the distress from returning in the future. Once the problem is assessed, then this information is used in the material selection and design of the recycled mixture.

The needs for the change or procedure for HIR will affect the construction methods, and possibly the equipment to be used as well. More specific information follows.

Reclaimed Asphalt Pavement (RAP)

Core sampling, using random location techniques is a common method to obtain samples of the existing pavement that will represent the project to be recycled. However, Caltrans prefers to take cores every 2,000 feet in an alternating pattern. For CIR, the preferred spacing is 1,500 feet. In a manner similar to that used for CIR, the HIR pavements must be evaluated using the methods outlined for evaluation in Chapter 3. Assessment of cracking, rutting, and other pavement defects will assist the engineer to determine the best method for designing the new recycled mixture. Once the cores have been measured and photographed, they should be trimmed, utilizing the topmost portion that is equal to the depth of recycling for the source of RAP to be used in the mix design. Tests on the material from the core samples should include at least the following:

- Bulk specific gravity or density
- Field moisture content (this will have an influence on the rate of production in the field)
- Asphalt binder content
- Properties of aggregate recovered from the RAP, including gradation, shape and angularity, etc
- Properties of the recovered asphalt binder, including the PG grading, and also other properties such as penetration, viscosity, temperature susceptibility, etc
- Maximum theoretical specific gravity of the existing mix, using crumbled core samples, for example
- Volumetric properties including air voids, voids in the mineral aggregate, and voids filled with asphalt

This information provides a starting point for the engineer to evaluate the existing state of the pavement and use it to assist in re-designing the mix to achieve the desired properties.

Asphalt Binder

The asphalt binder provides the best opportunity to change the properties of not only the binder itself, but the total behavior and durability of the recycled HMA. Recycling agents can be used to modify the existing asphalt binder to improve the performance and/or simply restore the original properties as needed (ARRA 2001).

HIR Recycling Agents

Recycling agents for HIR mixtures are typically hydrocarbons that will alter the binder in the existing pavement mixture to have physical and chemical properties that are beneficial to the performance of the pavement (ARRA 2001). The purpose of adding recycling agents is intended to:

- Restore the aged asphalt binder properties to a consistency level appropriate for construction purposes and the intended end use of the recycled mixture
- Provide sufficient additional binder to coat the RAP and any added aggregate
- Provide sufficient asphalt binder to satisfy the mix design requirements

Recycling agents may include materials such as soft asphalt binders, specialty products, and on occasion, asphalt emulsions (ARRA 2001). Soft asphalt binders are typically less expensive than other options, but have limitations in that they must be added to the RAP as a coating on virgin aggregate in order to get good dispersion. Specialty recycling agents are more commonly used and are more aggressive in their ability to alter the binder in RAP, and thus activate old binder that may be tightly bound to the aggregate. The choice of agent will depend on what the mix designer is attempting to achieve in the recycled mixture. One philosophy might be to assume the existing binder on the RAP is part of the aggregate, and that the new additives will not activate the binder in the RAP. Another approach is to attempt to restore original properties to the aged binder. It is generally agreed that recycling agents must have at least the following properties (ARRA 2001):

- Be easy to disperse in the recycled mixture
- Be compatible with the aged asphalt binder to avoid separation such as syneresis or exudation of paraffins from the binder. Also, if the recycling agent contains modifiers such as polymers, they must also be compatible with the asphalt in the RAP
- Able to disperse the asphaltenes in the aged asphalt binder
- Capable of altering the properties of the aged asphalt binder to the desired level.
- Are uniform and consistent from batch to batch
- Resistant to excessive hardening during the hot mixing phase to ensure long term durability
- Be low in volatile organic compounds or contaminants to minimize smoking and volatile loss during construction as well as reduce long term aging.

New Aggregate

Although rarely used in practice, new aggregates can be introduced during the HIR process in order to modify the gradation, and improve stability or stiffness as well as possibly correcting an over-asphalted mixture. This decision will be based on the performance of the original HMA pavement, and within the limit of the construction equipment's ability to accommodate additional materials (ARRA 2001). More likely, new HMA would be the practical method to achieve improved gradation of the final mix.

New HMA

On occasion, it may be desirable to add virgin HMA from a hot mix plant in order to improve the mix performance and/or provide a thicker layer as well as smooth high and low areas, as is done in pre-leveling. This change may be part of the HIR process of repaving and remixing. Similar to the addition of virgin aggregate, the gradation of the new HMA will need to be compatible with the RAP, as well as the rejuvenated binder in the original pavement. This can be done by remixing the RAP and the HMA into an integral blended layer. Alternatively, the new HMA might be placed on top of the just-placed recycled mix.

New Technologies

Variations on a theme have been proposed in the past, with only modest success. One idea is a system to transform an existing asphalt pavement to a two-layer pavement with open-graded mix on the top. This idea from Japan is called HITONE and uses HIR equipment to heat in place, but then separates the RAP into two size fractions. The finer fraction, essentially a mastic, is placed back on the roadway, followed by the coarser open graded fraction as a friction course that may also serve as a drainage layer and be quieter under traffic. This system has not been tried in the U.S. yet.

Warm Mixes

One of the difficulties with HIR is the ability to heat the RAP to sufficiently high temperatures in order to compact it back into a dense layer. Multi-phase heaters and scarifiers have been developed to overcome this problem, but in cool or windy weather, reaching adequate compaction temperature and maintaining it is not easy. There is a considerable move afoot to introduce additives and methodology that will allow HMA to be readily compacted at less than traditional temperatures and this concept could be extended to HIR.

13.3 MIX DESIGN

13.3.1 Philosophy of Mix Design

With both CIR and HIR, the establishment of the appropriate quality and gradation of aggregate for the intended purpose of load capacity, traffic, friction, durability, etc., must be done in conjunction with the practices in place for the class of road. Once that is done, then the purpose of the design is to put as much asphalt binder as possible into the mix to provide waterproofing and durability, but not so much that there is loss in stability and stiffness required to carry the intended traffic. The quality of the final mix in place should have sufficient compactability so that the required density can be achieved. CIR has the disadvantage of requiring additional fluids (water) to reduce the mix mass viscosity for compaction at ambient temperatures. HIR has the challenge of getting the recycled HMA heated sufficiently to achieve adequate compaction.

13.3.2 Cold In-Place Recycling Mix Design

The basic concepts of mix design for CIR are similar for most highway agencies, but there is no universally adopted procedure. Caltrans has established a mix design for CIR projects. It is a work in progress and is expected to be updated as State experience is developed. A summary of the key steps are presented below.

1. Obtain samples of RAP from the field. As briefly discussed above, core samples are taken from the existing pavement, both at the centerline and at the edge of the pavement, to determine the various characteristics of the existing layers and thickness of HMA. Care must be exercised to evaluate the uniformity of thickness and changes along the centerline of previous paving operations. The preferred method of obtaining samples for mix design is by using a milling machine that will produce samples similar to what will be achieved during construction
2. Determine RAP properties. Laboratory tests are conducted using the RAP core samples to determine the properties of the existing mixture. These properties include the gradation of the milled or crushed (if milling is not an option) RAP, moisture content, asphalt binder content, aggregate properties. This information is the basis for determining the properties and amount of added material, if any, to improve the recycled mixture.
3. Select the amount and gradation of new aggregate. In some cases, new aggregate may be needed to correct a mix that is over-asphalted, or to improve the stiffness and stability. Also, if there is insufficient material to make up the needed thickness of the recycled layer, then new aggregate or virgin HMA will be required. Although one option would be to mill deeper into the existing pavement, there may not be sufficient pavement thickness for this purpose.
4. Select type and grade of recycling additive. The most common recycling additives for CIR are asphalt emulsions or emulsified recycling agents because they are liquid at ambient temperatures, and can be readily dispersed in the recycling mixture. Some versions of these additives include

other modifiers such as polymers, used to provide enhanced setting and performance properties to the binder. Other mineral additives such as lime or portland cement are added to accelerated the setting and provide early stiffness, as well as improve water susceptibility such as stripping.

5. Estimate the amount of recycling additive. Past experience has shown that CIR mixtures that will not have aggregate added (100% recycle) require recycling additives in the range of 2% to as much 4% based on the total mix. The thickness of recycling in the field will also help determine the amount added. The actual starting point of the design will depend on local practice, experience, and other empirical factors. The type and level of activity (ability to soften the existing binder) of the agent will also determine how much of the old aged binder will actually be rejuvenated and become part of the binder system of the newly recycled mixture. The more aggressive, the less recycling agent will normally be required.
6. Determine liquid content for adequate coating. Water is typically added to CIR mixtures in order to provide enough total liquid to coat the aggregate and aid in the compaction of the final mixture. If an asphalt emulsion is used as a recycling agent, then some of the moisture comes from the water fraction of the emulsion. However, this recycling agent may not be sufficient to wet and coat the RAP and new aggregate (if any), so water is also added. This coating evaluation is done in the laboratory by using small samples of RAP and adding the previously-determined amount of agent to the RAP, and then thoroughly mixing in water in small increments, then observing the degree of coating. The optimum amount of coating is then determined by observing the minimum amount of added water that just coats the RAP and aggregate, and when additional water does not improve this coating. Moisture sensitivity and raveling should be evaluated.
7. Establish job mix formula. Following the mix evaluation and testing using compaction vs. total fluids content curves, a job mix formula (JMF) is established as a starting point for field operations. The JMF includes the amount, type and grade of recycling additive, the water to be added, as well as the aggregate requirements.
8. Make field adjustments. At the start-up of a project, the JMF is used to set the mixture parameters. It is recognized, however, that adjustments will need to be made for weather, variation in the RAP, and changed demand for recycling agent materials. Fine tuning of the mix may include adjusting the water content or even the recycling agent if observations show that coating is not optimum. Compactability is also very important when evaluating the mix during start up.

13.3.3 Hot In-Place Recycling Mix Design

As indicated earlier, the goal of HIR mix design is to restore the properties of the aged asphalt pavements to that of a new pavement, or at least as near as possible. To achieve this goal, the aged binder must be evaluated to determine the effect of oxidation over time. In addition, the effects of traffic on the pavement mixture due to densification and reduction in air voids must be evaluated. The mix design shall conform to Asphalt Institute Manual Series Number 2 (MS-2), Appendix A, “Mix Design Using RAP” using California Test 367 to perform Step 5.

In a manner similar to that shown for CIR, the summary is provided below.

1. Evaluate the existing HMA and determine mix properties. As indicated in the Materials section, the specific characteristics of the existing materials must be identified so that the type and amount of recycling agent as well as the need for virgin aggregate can be determined. Core samples must be carefully examined to identify the thickness of different pavement layers, previous surface treatments, interlayer geotextile paving fabrics, specialty mixes, evidence of material failure such as stripping, disintegrating aggregate or mixture, retention of moisture, and any tendency to delaminate (FHWA 2003). Once the core samples have been examined, they must be prepared as

outlined under the Materials section. In addition to cores, actual millings from the field equipment or a small milling machine used for this purpose might be generated in order to help determine how the HMA will behave under real construction procedures, and to provide materials for the mix design.

2. Determine the method for rejuvenating the asphalt binder. The next step of the mix design for HIR is to conduct laboratory testing of the original HMA to determine the best method to rejuvenate the aged binder. Three methods of rejuvenating have been successful, and these options are: a) use a recycling agent only, b) use a soft grade of new asphalt cement, or c) use a combination of recycling agent, new asphalt binder, and new aggregate. In lieu of this last option, virgin HMA could be considered for an addition to improve the mix and/or add more material for a thicker pavement layer. It is imperative that the nature and reactivity of the recycling agent be understood so as to avoid undesirable consequences after the project is complete.
   Select the type and amount of recycling agent. Traditionally, this step has been to determine the viscosity of the aged asphalt, and then add sufficient agent to restore the original or desired properties. However, more information may be required to predict the future behavior and longevity of the recycled pavement by using the Performance Graded (PG) system developed for Superpave. The tests used in the PG grading system are intended to match not only the material properties, but the climate or location where the binder will perform well. Using viscosity alone may mislead the designer as to expected performance. The steps or process to achieve this phase of the mix design consist of the following:

   - Obtain representative field samples
   - Extract and recover aged asphalt binder, and determine a) binder content, b) viscosity and penetration of the binder, and c) other properties necessary to grade the original binder in the PG procedure, if desired
   - Use viscosity blending chart to determine the amount of recycling agent required to rejuvenate the aged asphalt binder
   - Make adjustment in the field to the recycling agent application rate based on mix appearance and QC/QA test results during HIR construction

3. Prepare and test mix specimens in the laboratory. Mixtures are made up in the laboratory, to include a range of RAP, recycling agents, new aggregates, new asphalt binder, and possibly new HMA. Test specimens are made for evaluating mixture properties. Tests normally used in mix design procedures such as stability, stiffness, water sensitivity, and others are used to determine the optimum combination(s).

4. Establish job mix formula. Once all laboratory analysis of materials has been completed, the information is available to establish the job mix formula which includes the optimized properties and meets any economical goals or limitations.

   The JMF should include the following information:

   - Asphalt binder content (%), penetration at 25ºC and viscosity at 60ºC of the asphalt binder contained in the asphalt pavement to be recycled using ASTM Method D-2172. Alternatively, the properties used to classify asphalt binder using the PG system may be used.
   - Gradation of the aggregate in the asphalt pavement to be recycled (after extraction of binder) using California Test 202
   - Gradation of aggregate and percent asphalt of the virgin HMA added to the mixture
   - Proposed asphalt binder grade, source, and properties (as specified in Section 92, “Asphalts” of the Standard Specifications)

- Source and properties of the aggregates, as specified in these special provisions, proposed for use in virgin hot mix asphalt
- Source, type, amount, and properties of recycling agent per Section 92 or 94 of the Standard Specifications
- Aggregate gradation (including recycled pavement plus virgin hot mix asphalt) and asphalt content of the recycled asphalt concrete mixture (including recycled pavement, virgin hot mix asphalt, and recycling agent)
- Stability and volumetric analysis information of the recycled mixture as described in California Test 367
- Penetration at 25ºC and viscosity at 60ºC and 135ºC of the binder in the combined recycled mixture (includes recycled pavement, virgin hot mix asphalt, and recycling agent)

13.4 CONSTRUCTION

13.4.1 Cold In-Place Recycling Construction

The construction process, sequence of operations, and the equipment type for CIR are usually dictated by the specifications, the contractor's experience, and the specifics of the project. All pavement evaluation work needs to be completed prior to a contract being awarded, except mix design which is done as part of the contract. The Caltrans construction specifications for CIR are in Reference 13. The CIR construction process includes as least the following operations:

- Preparation of the construction area
- Surface pulverization and sizing of the RAP
- Addition of new aggregate if necessary
- Addition of new RAP if necessary
- Addition of new asphalt binder/recycling agent
- Mixing
- Placement
- Aeration
- Compaction
- Curing
- Application of pavement wearing surface

A general view of the construction process is shown in Figure 13-2. There are several possible arrangements of equipment and process details that can be selected by the contractor, but Figure 13-2 shows that some choices such as a single-unit train combines several operations. All steps or operations may not be necessary on some projects.

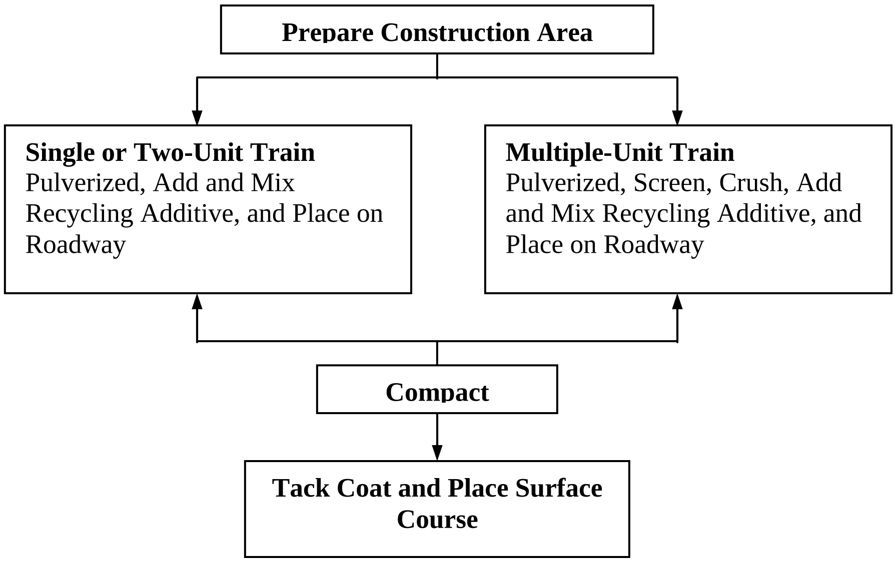

Figure 13-2 CIR construction flow chart (ARRA 2001)

Preparation of the Construction Area

Prior to construction, the pavement should be evaluated to identify any areas where material properties or pavement thickness appear to be non-uniform. Any areas displaying insufficient support, such as localized soft areas, must be corrected prior to recycling due to the risk of damage to construction equipment or premature failure following construction. Weak material should be removed and replaced with suitable patching material. Portions of the project that were noted in the preliminary evaluation and mix design phases should be identified on the roadway and the field personnel made aware of these changes (ARRA 2001). For example, the current CIR project may span more than one prior project where asphalt materials were different.

Construction Process

The process of CIR construction combines the several steps, including milling, material sizing, adding aggregates/HMA/recycling agents, mixing, and laydown. There are two methods that are typically used in the CIR process, including:

- Single unit train
- Multi-unit train

These methods are described in the paragraphs below, and largely come from ARRA, 2001.

Single Unit Process Train

The single unit train does all the steps with a single piece of construction equipment, including removing the asphalt pavement to the required depth and cross-slope, sizes the RAP, blends all additives with the RAP, and places the material back on the roadway. Traditional single unit trains do not contain the equipment to screen and crush the RAP. Single unit machines must contain a breaker bar or some other means of sizing the RAP. A schematic of a single unit full depth recycling machine is shown in Figure 13-3 and can be compared to the single unit CIR recycling train shown in figure 13-4.

A single unit CIR train may actually contain more than a single piece of equipment, but because they act in tandem, are essentially "single units". In the unit shown in Figure 13-3, the first component mills and mixes the existing pavement surface with recycling agent and deposits the recycled mix in a windrow on the roadway. A separate paving machine follows closely behind the recycling machine, picks up the windrowed material and lays it back down on the roadway in the final configuration for the pavement surface. Note that although there is a truck with the asphalt emulsion recycling agent, and a compactor, these are still considered part of the single unit.

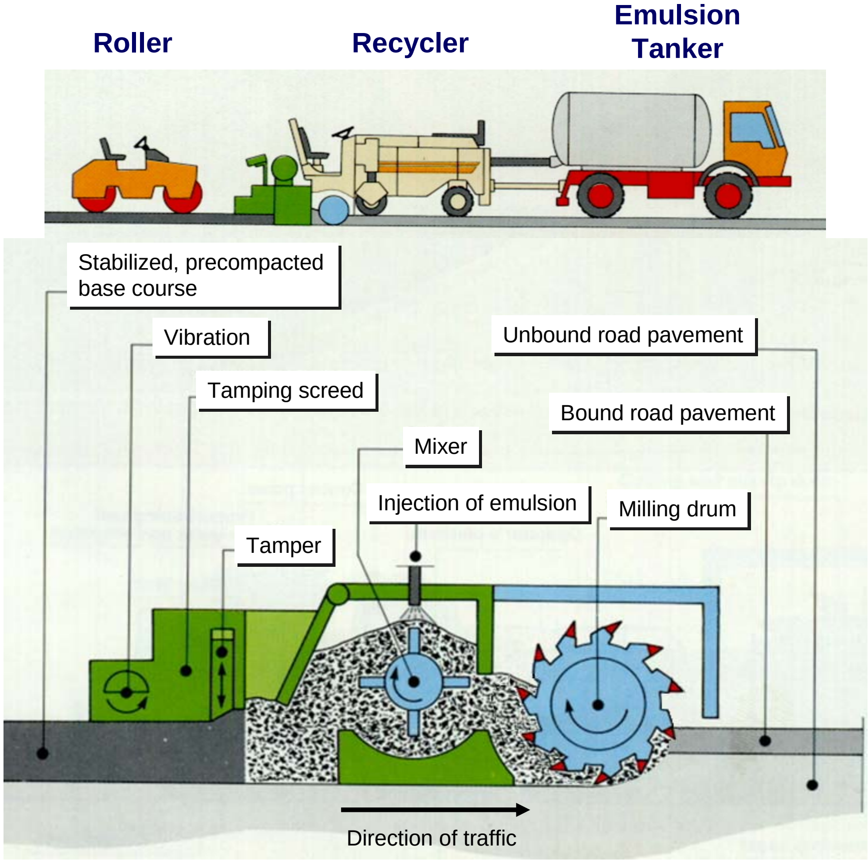

Figure 13-3 Schematic of Single Unit Full Depth Recycling (FDR) Train (Kandhal, et al 1997)

New materials such as aggregates or other dry additives such as lime may be spread on the existing roadway ahead of the unit prior to milling. The milling machine then can pulverize the existing material as well as mix all ingredients in a single operation. Two other single unit machines are shown in Figures 13-4 and 13-5.

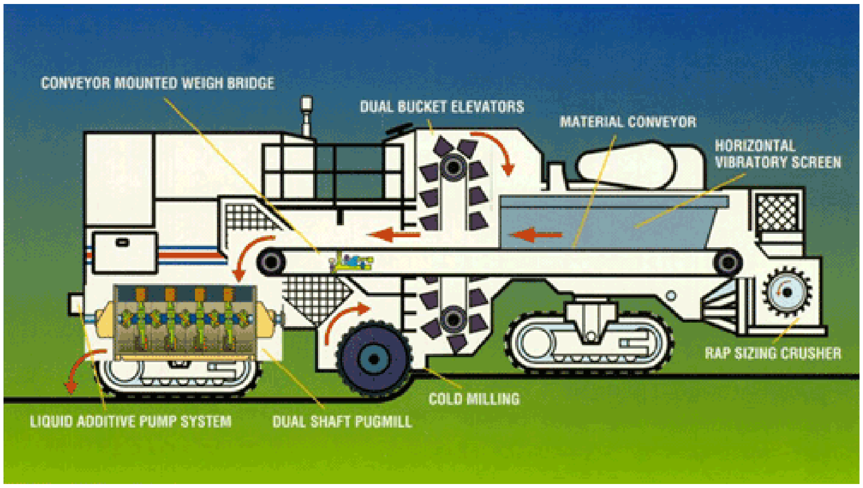

Figure 13-4 A Variation of a Single Unit CIR Train (Kandhal, et al. 1997)

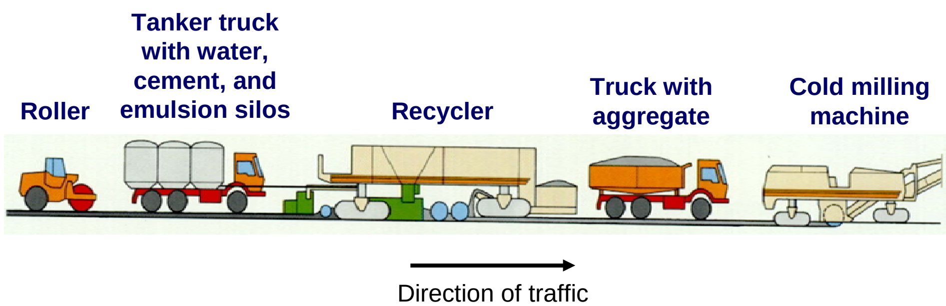

Figure 13-5 A Multi-Unit Train that Allows for Addition of Virgin Aggregate (Kandhal, et al, 1997.)

The single unit trains have the advantage of simplicity of operation and high production volume. It is also easier to operate in tight quarters such as urban streets with short turning radii due to its short configuration.

Two-Unit Train

Many CIR trains incorporate pugmill mix-pavers as an integral part of the train. The two units include a large, full-lane width milling machine and a pugmill mixer-paver. One of these units is shown in Figure 13-6. These trains are essentially large cold mix pavers with the added feature of a metered pugmill in the chassis. The milling machine removes the RAP, and the sizing of the RAP is similar to the single unit. The RAP is deposited directly into the large pugmill of the mixer-paver, and has the ability to be weighed on the feeder belt, and then the liquid recycling agent/asphalt emulsion proportioned accordingly. The completed mix then goes directly into the spreader-auger system and placed in its final form.

Advantages of the two-unit CIR system is more accurate proportioning that results in a more uniform mix, simplicity of operation, and high production capacity. It is also relatively short, and can be used effectively in urban areas and where turning space is limited.

Figure 13-6 Two-Unit CIR Train in Operation (FHWA 2003)

Multi-Unit Trains

The configuration of a multi-unit CIR train is longer than other trains, and consists of a milling machine, a trailer mounted screening and crushing unit, and a trailer mounted pugmill mixer (in many cases, the screening, crushing, and the pugmill mixer are all combined in one unit) a pick-up conveyor, and a paving machine. A sketch of a typical train is shown in Figure 13-7. The milling machine cuts the pavement to the desired depth and profile as well as cross slope shape, then deposits the RAP into a crushing and screening unit. All material is passed over the screens and oversized material is sent to the crusher, which is usually an impact type, then the crushed material is returned to the screening unit for resizing. From the screens, the RAP goes into the pugmill mixer on a conveyor weigh belt that weighs the RAP. The liquid recycling agent is added at the pugmill using a computerized metering system that is locked into the feed belt for accurate measurement and control. The recycling agent is pumped into the twin shaft pugmill for thorough blending of the agent and RAP. Experience has shown that these computerized systems have a high degree of quality control and high productivity. From the pugmill, the completed mixture is deposited into a windrow or directly into the hopper of the paver. A windrow elevator is typically used to place the mix into the paver rather than be locked to the train, providing flexibility in speed and operation of the paver. The final step for the CIR train is to place the recycled mix on the roadway.

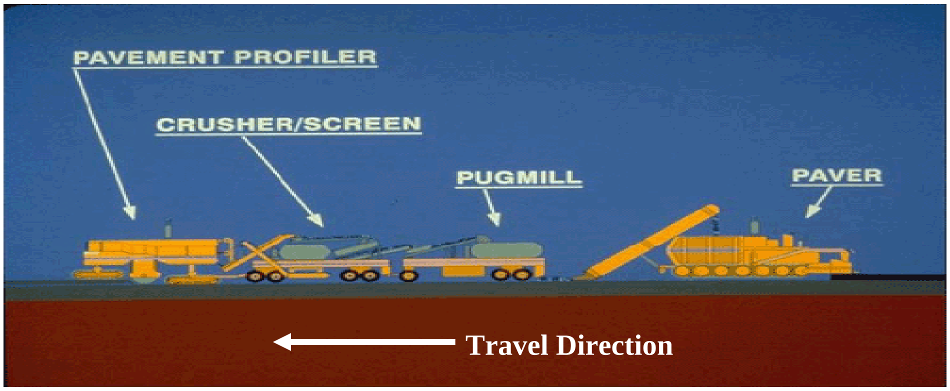

Figure 13-7 Schematic of Multi-Unit CIR Equipment Train (Kandhal, et al 1997)

The multi-unit CIR trains have been found to provide the best process control, uniformity, and production, often more than two miles per day. A disadvantage is its length and difficulty in operating in urban streets, as well as complex traffic control.

Aeration, Compaction, Curing, and Surfacing

As noted in the discussion of mix design for CIR, additional fluids are added to the mixture to promote good mixing, coating, and compaction. But this added moisture, particularly any added water and the water that is part of the asphalt emulsion must be allowed to evaporate once the pavement is in place. Aeration also improves stability after placement, so that compaction equipment is more effective. The rate of evaporation will depend on many factors, but probably the most important is the weather, with CIR being most successful when it is dry and warm. The factors that impact the rate of evaporation include the type of asphalt modifier, gradation or permeability of the aggregate, and weather factors such as temperature, wind velocity, humidity, and shade from trees. Minimizing additional fluids in the design and construction process will also speed up the aeration process, and may even allow placement with a conventional paving machine. (Kandhal, et al 1997)

CIR mixes are stiffer than HMA mixes and require additional compaction effort. Heavy pneumatic and vibratory drum steel compactors must be used to break down the mix, and even with these, it is not feasible to achieve the same densities as with HMA. The best procedure is to determine the optimum amount of total fluids early in the construction process. It is recommended that compaction commence as the asphalt emulsion begins to "break", or turn from brown to black. The time for the mix to break will vary with the type of emulsion or recycling agent, and/or the weather, but typically the target will be from 10 minutes and up to 2 hours. It is advisable to work closely with the supplier of the emulsion in order to obtain best results on any given project. When finally compacted, the total air voids in CIR mixes are typically much higher than for HMA mixes, often in the range of 9 to 15 percent (Kandhal et al 1997 and ARRA 2001). While these voids may not be desirable for pavement performance, they do enhance the ability of the mix to dry. Further reduction in air voids is obtained in many cases by re-rolling after curing and prior to the surface application

Compaction of CIR is an important part of the construction process, because poor compaction can lead to premature failure or poor performance in terms of smoothness, load capacity, resistance to rutting and shoving, and disintegration. Typically, a combination of vibratory steel wheeled and pneumatic rollers are used to get to the final density. Breakdown rolling is usually accomplished with a steel drum roller in the static mode to seat the mix into place and provide a relatively smooth starting point, before the pneumatic compactor gets onto the mat. The heavy pneumatic roller will further seat the mix into its maximum density, but will distort the mix, especially along the edges of the mat if it has not been seated with the steel drum roller. Under the action of the heavy (25 tons) pneumatic-tired roller, the mix will continue to break down and increase density, but may leave tire marks in the surface. Roller marks can be removed by finishing compaction with a vibratory steel wheeled roller. The optimum compaction and rolling patterns should be established early on a project using a test strip, experimenting with the type of roller and number of passes to achieve maximum density (ARRA 2001).

The CIR pavement will have a high load carrying capacity because of rock-to-rock contact, but the high void content will cause premature damage such as raveling if a wearing surface is not applied when the curing process is complete. The compacted CIR pavement must be adequately cured before a wearing course is applied. The curing period is typically two days to two weeks depending on environmental condition prior to applying a wearing course, and traffic speed may be controlled during this period to reduce damage. However in many instances a fog seal is applied at the end of each recycling day to minimize raveling.

Similar to the aeration process, the curing process is the continuation of the evaporation of water and volatiles in the asphalt emulsion as well as water from the mixture. Aeration is the removal of free water that was added for compactability that can readily evaporate from the air voids. Curing is the process of the asphalt emulsion converting from the emulsified state through removal of water and other fluids. As the water in the asphalt emulsion evaporates, the dispersed asphalt particles then coalesce into a continuous asphalt film that coats the aggregate. When curing is complete, the mixture has reached its near maximum strength and it is appropriate to apply the wearing course. The initial curing period may vary from a few days up to two or more weeks, and the strength gain will continue with time, depending on factors such as:

- Temperature, both day and night
- Permeability
- Rain and/or humidity levels
- Moisture content of the recycled mix
- Level of compaction and in-place voids
- Moisture content of the subbase, and shoulders

The curing period may be dictated by the need to place the road back into service, impending poor weather, and other factors. Selection of the materials and recycling additives will play a key role in determining an acceptable or desirable curing time.

The primary purpose of the wearing course is to protect the CIR pavement, providing an umbrella to shed water off the surface and onto the shoulders and drainage system and to prevent the abrasive action of vehicle tires from degrading the surface. For roads with low traffic volumes, single or double chip seals have been shown to be effective. However, some roads may require fog seal only if the traffic is low, and curing is adequate. For higher volumes of traffic, HMA overlays have been used, typically in the range of one to two inches thick.

13.4.2 Hot In-Place Recycling Construction

In a manner similar to that for CIR, the HIR process has variations, depending on the type or extent of surface recycling desired. These methods were largely developed as innovations by contractors, and then adopted by agencies such as Caltrans, who then wrote specifications to attain the desired results. There are three processes that are currently utilized: surface recycling (also called heater-scarification), repaving, and remixing. Currently Caltrans only has a HIR specification for remixing. A future specification may be developed for repaving. There is need to improve the air quality associated with HIR, and a future specification may include this requirement. All of these methods are aimed at heating the surface of the existing HMA and then restoring the damaged or worn surface to new-like condition.

Surface Recycling (Heater Scarification)

Surface Recycling (also known as heater scarification) is the earliest form of HIR and was widely used in the 1950s, 1960s, and early 1970s. It is a simple process in which the surface of the old pavement is heated, scarified with a set of scarifying teeth, mixed with a recycling agent, then leveled and compacted (8). Scarification depths of up to 1 in were possible, but more commonly, effective scarification was limited to about ½ to ¾ in. No new aggregate or other materials were added during the process, but a new wearing course was often added later. Figure 13-8 is a schematic of a typical heater-scarifier equipment set up.

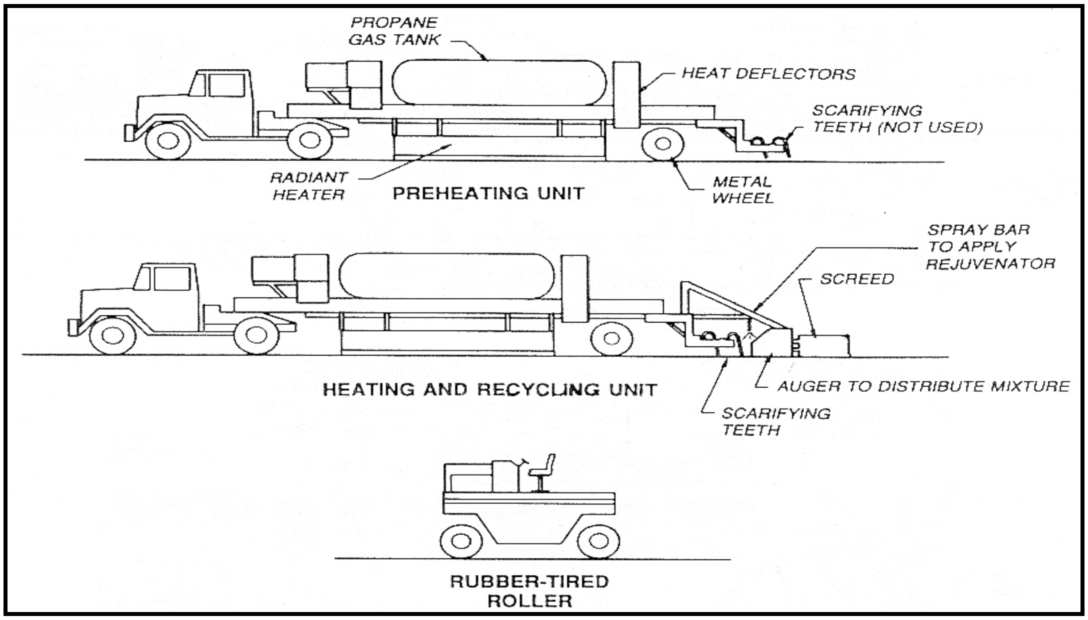

Figure 13-8 Surface Recycling Process (Heater-Scarification) (Button et al, 1994)

Early attempts at heating using direct flames were not particularly successful because it caused smoking and excessive hardening of the asphalt binder. Later methods utilized infra-red heaters fired by propane gas, and proved to be better at minimizing the problems with direct flame. One or more heater units were used in tandem to gradually raise the surface temperature of the pavement so that the scarifying teeth could scrape through the surface. Mix temperatures up to 300°F were possible when using two pre-heaters. The scarifying teeth on this type of equipment were usually spring-loaded tines that could ride over obstructions such as man-hole covers, but they had limited ability to dig very deep into the warmed pavement since the temperature decreased with depth. The combination of normal asphalt aging and additional hardening from heating typically required that a liquid recycling agent be added to soften and restore the binder properties. Blending the recycling agent into the loosened surface mix was a challenge without additional stirring and mixing. Most surfaces restored using heater scarification were overlaid with new HMA as a final wearing surface.

Repaving

Repaving is a process where the existing pavement is heated, scarified, or milled to a depth of up to 2 in, and the millings mixed with a rejuvenating agent. This recycled material is then placed as a leveling course and followed up with a HMA wearing course, forming a hot thermal bond between the existing and new layers. These two operations can be completed in a single pass using special equipment, or, using a two-pass process including a heater-scarifier and conventional paving equipment. Figure 13-9 shows an example of a single pass repaving equipment train.

Current repaving practice is to preheat the existing pavement surface to about 375 °F using infrared pre-heaters as well as heaters in the repaving unit as well. The heat-softened pavement material is then removed to a depth of about ¾ in, depending upon how efficient the heater is at penetrating and softening the asphalt. Some repaving machines utilized a milling head that allows the process to mill deeper than might be accomplished using a scarifier only. For the machines with milling capability, there is usually the option to adjust the depth and cross-section of the pavement during the operation, as well as adjust the milling head to avoid obstacles such as manhole covers.

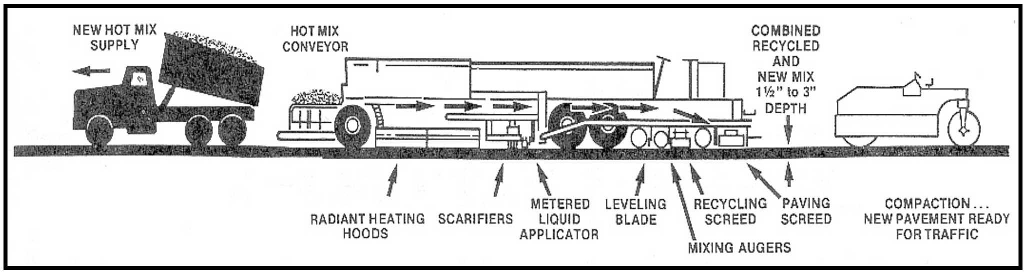

Figure 13-9 Single-Pass HIR Repaving Train (Button, et al 1994)

The amount of rejuvenation of the old asphalt pavement material is determined in the laboratory, then applied in the field, by spraying directly onto the roadway, onto the windrow, or directly into the mixing chamber. This predetermined rate of rejuvenator is set in the machine, and locked into the rate of forward progress so that a uniform mix results. Mixing of the recycling agent is usually accomplished on the roadway surface by augers that transfer milled material into a windrow, and then also auger the material into a new shape and levels the recycled mix. The new HMA material is then added and spread with a second screed directly on top of the recycled layer. The goal is to bond the new HMA layer to the recycled pavement surface, and this is readily accomplished if the recycled layer can be maintained hot (~215 °F). Weather and forward progress of the repaving process will usually affect the success to a significant degree. Depending on the design of the repaving equipment, a well-shaped and uniform lift thickness may be constructed using manual or automated controls. Repaving has been shown to be a practical method to restore and old asphalt pavement in a single pass of the equipment.

Remixing

The remixing method of HIR is used when the pavement requires additional aggregate or HMA to improve the gradation or thickness of the recycled pavement. The depth required to correct defects such as cracking is also a consideration. Heating the existing pavement up to about 230 °F (average for the material) or higher is feasible when the existing pavement is reasonably dry, the weather is warm, and the wind is minimal. Each unit in the paving train usually has a heater (propane or diesel fueled), including a heater on the remixing unit. The heaters and the remixing units are usually full lane width, and may range up to 40 ft long. Depending upon how many heater units are used, the HIR may range up to 200 ft long, and require considerable space to operate. Figure 13-10 shows one arrangement for a remixer train.

Most remixer units use rotary milling heads to remove the surface of the existing pavement rather than tines. Less power is required for warmed pavements as compared to cold milling operations. It is difficult to heat the pavement to a depth of 2 in, the usual target depth for this HIR process. Heat penetration into the existing pavement is inefficient and slow, and may overheat the surface. Some equipment manufactures have developed staged milling (two-step is most common) process where each pre-heater has a milling head and removes only a portion of the heated pavement, say 1 in. Following units will also heat and remove 1 in, until up to 3 in depth has been achieved. This staged process is gentler on the RAP, and does not break aggregate, nor take as much power where each layer is warmed sequentially, and higher mix temperatures may be attained. The heated RAP is then typically mixed with a recycling agent in a pugmill in the final remixer unit. Figures 13-10 and 13-11 are examples of this process and there are other configurations used by contractors.

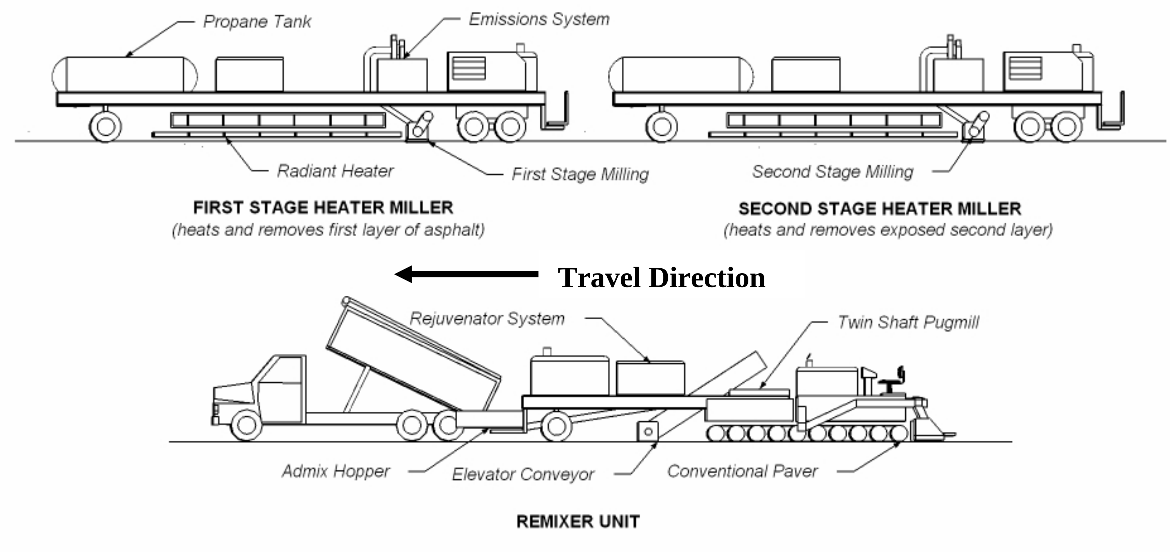

Figure 13-10 Example of a Remixing Process HIR Train (Wiley 2007)

Figure 13-11 Example of a Remixing HIR Train in Action (Wiley 2007)

The virgin HMA is usually received in the hopper of the paving machine following the remixer unit. However, some trains are set up to deposit the HMA in a windrow ahead of the remixer in order to take advantage of the added mixing, and also to increase the average temperature the recycled mix from the higher-temperature. Early systems have attempted to do all of the mixing on the pavement surface after milling, but this practice was not particularly successful. Multi-step heating and milling and stirring on the grade, coupled with a pugmill has been more effective.

Re-laying the recycled mixture has been accomplished by two different methods. The first method has the paving machine snugged up close behind the remixer unit and the recycled material drops directly into the paver hopper. In the second method, the recycled mixture is dropped into a windrow behind the remixer unit, and then picked up using a conveyor to deposit it into the paving machine, where it is laid in the same manner as new HMA, then compacted.

One of the restrictions of the remix process is that the volume of virgin HMA that can be added is limited to 20% in order to preserve grade elevations with respect to adjoining shoulders. One efficient method developed that enables increased volumes of virgin HMA to be added (up to 50%). In this process, a narrow center strip is first cold-milled from the road surface to provide space for temporarily holding the RAP just removed. Not only can increased amounts of hot virgin HMA be added to improve gradation and binder properties, but the heat transfer from these materials reduces the temperature that must be applied to the existing road surface. An example of this approach is shown in Fig. 13-12.

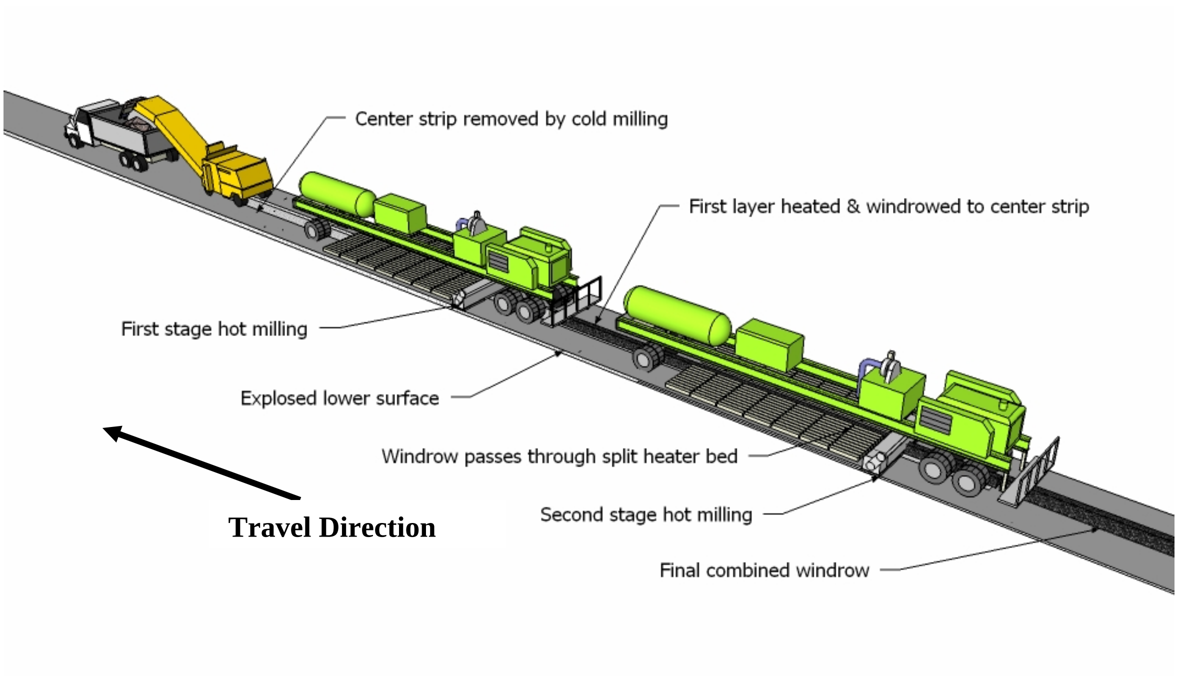

Figure 13-12 Example of Remixing HIR where the amount of virgin HMA can be increased by milling a trench to accommodate the HMA, providing additional heating. (Wiley 2007)

13.5 QUALITY CONTROL

13.5.1 Quality Control of CIR

Quality control is essential to any successful CIR project, and good practice must be followed regardless of the specifications. The need for consistency and uniformity in all aspects of a project is constant in order to achieve the anticipated results of good quality, strength, and durability. Observation and experience have shown that several areas of poor practice are most often responsible for poor projects (Grogg, et al 2001).

- Poor control of added asphalt binder or recycling agent. Inconsistent amount of recycling agent will result in too soft of a mix when too much is added and too hard when insufficient agent is added. Inadequate bonding of the binder and aggregate may also occur when insufficient agent is added
- Inconsistent mixing of all materials that may be caused by factors such as too fast of forward progress
- Poor compaction and resulting inadequate density
- Placement of a tight seal or dense-graded wearing course too soon after construction. Good weather is required to properly dry and cure the CIR mix before it is covered with an overlay or seal coat. If the surface is placed too soon, water can be trapped in the pavement, leading to

accelerated stripping and rutting due to lack of strength. Even under good conditions, this process may take up to two weeks to get the moisture content down to a desirable level of less than .5 percent

- Depth of recycling. Surface recycling is intended to remove only a partial depth of HMA, leaving a layer for bonding with the recycled mix. If the depth of milling is too great, there will be a loss of bonding if the milling cuts through the HMA and into the unbound base course, but more importantly, there will result variable mix properties
- Wet weather. If there is significant rain following CIR construction, and before curing has concluded, the asphalt emulsion may wash off the aggregate with serious loss of bonding and ultimately project failure

Variability in the HMA along the length of a roadway is inevitable, ranging from patches to change in design or thickness from previous projects or contracts. A good QC plan should be able to accommodate these variables encountered in CIR:

- Gradation of aggregate, binder content, and moisture content of RAP
- Amount of recycling agent to be added
- Extent of patching, and other anomalies in the roadway
- Nature and amount of distress such as cracking or other deterioration
- Final compacted density of recycled pavement

A good QC plan should also be able to identify the target levels of variability and provide guidance on how to address the variables when encountered during construction. The plan should be flexible and nimble enough to allow for changes “on the fly” as they are encountered. In order to meet the Caltrans specifications and for quality control, there are specific actions that are required.

A given project should be divided into lots of 3000 sq yd, and the CIR operations should include the following factors:

1. Measure the actual recycle depth at each end of the milling drum every 300 ft along the roadway.
2. Measure the amount of emulsified recycling agent used to an accuracy of 0.5 % of the dry weight of recycled material shown in the JMF, by recording the amount used for each lot and comparing to that computed for the dry mass of processed RAP.
3. Measure the in-place density of the compacted recycled material using a nuclear density gauge when possible.
4. Sample the recycled material behind the screening equipment and test for gradation. For every third sample taken, determine the wet field gradation for sieves from 25 to 4.74 mm, and compare to the design, then adjust the emulsified recycling agent accordingly. Note that the fine fraction passing the 4.74 mm sieve is the most important for controlling the binder content.
5. The contractor is required to provide specific information for each lot as part of the Contractor Quality Control program of Caltrans, including:
   - Length, width, and depth of cut, and calculated mass of RAP processed.
   - Amount of emulsified recycling agent used, and compared to the amount of RAP processed.
   - Amount of any dry additives used and compared to the amount of RAP processed.
   - Maximum particle size in the RAP, prior to adding emulsified recycling agent.
   - Nuclear gage readings of in-place density at random locations.

- Plot the compaction rolling (passes) vs. density, containing the time and location of the test strip, which is used for relative compaction comparisons.
- Record of the ambient and compacted recycled surface temperatures.

13.5.2 Quality Control of HIR

The requirements for quality control of HIR are similar to those for conventional HMA. However, due to the wide variation in HIR construction equipment and methods, any generic QC plan will need to be adapted to accommodate local conditions and specifications, such as those of Caltrans. As an example, a QC plan for a project using the heater scarifier method will have only one component, while a quality plan for a remixing or repaving project will have two components: one for the HIR portion of the project, and one for the admix or HMA added to the integral overlay portion of the pavement. In general, experience has shown that the following areas need to be addressed in the QC plan for HIR projects (ARRA 2001).

- Heating of the existing HMA pavement
- Treatment depth
- Addition of recycling agent and admixture
- Placement of recycled mix
- Compaction of recycled mix

These five areas of concern regarding QC are discussed in the following sections.

Heating of the Existing HMA Pavement

Heating of in-place HMA is probably one of the greatest challenges. Getting heat into a dense layer of pavement is difficult when one must balance the rate of heating and softening with the rate of production. Oxidation or age hardening of the asphalt binder in the existing HMA needs to be minimized while at the same time ensuring that:

- Any excess moisture has been removed. Many older asphalt pavements have water trapped in the voids and considerable energy is required to evaporate the water before the mixture can be heated above the heat of water vaporization temperature (212 °F)
- The asphalt pavement is softened sufficiently so that it can be scarified and/or milled without excessive aggregate breakage. Although some equipment is designed with lower powered milling heads, they may not be able to mill to the desired depth. Other equipment is designed with more powerful milling heads that will essentially cold mill to the required depth (2 in, for example), and then use the heating units to heat the loosened HMA on the roadway surface, being more efficient in heat transfer. Still others will heat and remove the HMA in stages, heating and milling, with each pass of a heater/miller
- The recycling agent and admix can be thoroughly mixed in
- An adequate temperature has been attained and maintained for compaction of the final mix

Because of the variable nature of the HIR process regarding forward speed, materials composition, and need for recycling agent, it is difficult to determine the uniformity and compliance with specifications on a continuous basis. Although overheating and aging the asphalt can be measured in the laboratory on samples collected from the jobsite, it is not practicable to do so "on the fly". There are really no rapid tests for this purpose. However, there are a few observations and indicators that may be useful to help achieve the desired results:

- Emissions are good indicators as to what is happening during heating. Those that are white and dissipate quickly are from the vaporization of water in the HMA
- Blue or black smoke emissions indicates that some overheating or combustion is occurring, usually the more volatile hydrocarbons in the binder. Corrective action is required immediately, including one or more of the following: increasing forward speed, decreasing the intensity of applied heat by turning the burners down, or raising them off the pavement surface
- Observation of scorched or charred pavement surface
- Excessive temperature variations across the mat

Heating of the pavement surface should be as uniform as possible in both the longitudinal and transverse directions. This helps to ensure that the temperature, treatment depth, and compaction is uniform. Monitoring the temperature during the HIR process is necessary on a constant basis, in order to optimize uniformity. Some equipment have on-board thermocouples or thermometers that measure temperature, reliability and durability of these instruments is often in question. More useful are the hand held infrared heat guns that that can be used at any point in the HIR process, allowing the operator better control. But the heat gun measures temperature only at the surface, so material must be moved aside in order to get a better assessment of overall temperature.

Temperatures should be checked and monitored continually at several locations within the HIR process. The locations to monitor and for making immediate adjustments will depend on the equipment configuration, but should include at least the following:

- After each pre-heating unit
- Prior to final heating
- Prior to final mixing
- Immediately behind the paver screed

Treatment Depth

Uniformity of treatment depth is desirable and critical to the consistency of the HIR process. A number of methods have been used to determine HIR treatment depth, with varying degrees of success and include:

- Precision level surveys before and after scarification
- Measurement at the outside edges of the pavement after scarification and/or milling
- Marking out a known area, removing and weighing the loose scarified material, then calculating the depth based on the final density
- Using a probe or dipstick to measure the depth of uncompacted mix behind the paver screed
- Measurements from compacted core samples

Whichever method is use, a number of measurements must be made to represent an average depth. There are exceptions to achieving a uniform depth, for example when the HIR process is used to adjust the cross section of the roadway. The crown may need to be increased or decreased, or the curb may be in need of adjustment as well. In these instances, longitudinal uniformity is desirable, but laterally, the cross slope may be changed as part of the design.

Addition of Recycling Agent and Admixture

The addition of recycling agent is a key part of the QC operation and needs to be linked to the forward progress and treatment depth of the recycling unit. Modern recycling trains have incorporated microprocessors and/or positive displacement pumps to add the liquid recycling agent at the design rate. The set rate will depend on the depth or recycling, and can be set at the beginning of a project, and then adjusted and fine tuned over the first portion of the project. This calibration process would best be done in a test strip prior to beginning a project, but with a long recycling train, this is impractical because of the space required if it is off site. The agent can be linked to the forward speed of the HIR train, but the depth of treatment needs to be constant since there is no sensor to measure depth; the process needs to be monitored manually on a constant basis for uniformity in final results. The accuracy and variations of the addition of agent will have an effect on at least the following factors:

- Asphalt binder content of the recycled mix, including the recycling agent
- Rheology of the binder
- Compaction properties and uniformity
- Void content of the recycled mix
- Strength and durability of the recycled mix

The tolerance for the variation in added recycling agent is typically ±5% of the agent added as specified. The measurement of this rate can be made using a microprocessor or flow meter that accumulates the amount added over time/distance. A further check on application rate can be made by checking the tank manually on a regular basis.

When new HMA, aggregate, or other admixture is added to the RAP, a similar linking of forward progress to the rate of added material is also required. The equipment that can handle this admix material usually also can measure the rate using a microprocessor on a calibrated weigh belt. Tolerance of the rate of application may typically be in range of ±5 % of dry weight of recycled mix. A further check on the rate of admixture can be measured by matching truck weigh tickets to forward progress of the train and calculating the resulting rate of application. The application rates should be checked regularly, such as every hour, in order to keep tabs of the uniformity.

Placement and Compaction of Recycled Mix

Once the recycled mix leaves the HIR recycling and mixing process, it is placed using the same techniques as for new HMA. Some HIR trains have a screed on the last unit, usually with a pug mill, and the mix goes directly onto the roadway or into a hopper where it is spread in the normal manner. Other trains may be followed by conventional paving machines that have their own screeds. When admix material, especially HMA, there is opportunity to reshape the cross section of the roadway to the intended final position. Even though the hot milling of the recycling units attempt to shape the pavement, variations still occur and this final laydown operation provides the opportunity to finish the pavement as designed.

Compaction is accomplished using conventional steel wheeled and pneumatic tired rollers in a manner similar to virgin HMA. A test strip is required to determine the optimum roller combination and passes to achieve the necessary density. With HIR mixes, especially when full depth of 2 in is used, it may take more compactive effort to achieve the desired final density because it is also more difficult to reach and maintain adequate temperature required for compaction. Consequently, a combination of heavy vibratory rollers and pneumatic rollers may be required. Although the temperature and mix stiffness are crucial, an additional factor is the gradation of the aggregate. A combination of the aggregate gradation in the milled RAP (with some aggregate breakage that may not have been observed in laboratory samples) and aggregate in the new HMA must meet the specified gradation for the final recycled mix. It is highly likely that adjustments and fine tuning of the JMF for the HMA mix will be necessary after results from the test strip and early construction behind the recycling train are evaluated. More frequent sampling and testing early in the project is generally necessary to establish the correct proportioning. Density is usually monitored using a nuclear gauge that has been calibrated to the field core samples.

Specific requirements by Caltrans for the Quality Control of HIR projects for the remix method include:

- Measurement of the actual recycle depth on each side of the milling or scarifying machine at least every 100 m along the roadway length
- Following compaction, but prior to opening the roadway to traffic, the relative compacted density must be at least 92 % of theoretical maximum density

Each project must be divided into lots of 3,000 sq m, and the following information provided for each lot:

- Length, width, and depth of cut, and the calculated mass of RAP processed
- Amount of recycling agent used, compared to the amount of RAP processed, in percent
- Asphalt binder content of the in-place HIR mixture based on California Test 382
- Amount of HMA, aggregate gradation in the virgin HMA, and the amount (%) of asphalt binder in the HMA
- In-place density and relative compaction at three locations, using California Test 375, except in Part 5, substitute maximum theoretical density (Rice Method), using California Test 309, test for maximum density (TMD)
- On a daily basis, sample the HIR mixture at a selected location, split the sample, using one split sample for measuring the maximum theoretical density (Rice Method) based on California Test 309; the second split sample is retained by the engineer
- Every other day, sample the HIR mixture from the mat prior to compaction and test for Hveem stability using California Test 366 for information purposes

13.6 TROUBLESHOOTING IN THE FIELD

There is ample opportunity for achieving excellent results when constructing CIR and HIR projects. However, one must be diligent and follow a well thought out QC plan in order reach the intended final goal. Conditions may change, and then the uniformity and balance of the various components of the process may need to be adjusted. For example, a change in the weather, materials encountered, or construction equipment calibration may contribute to the need for continuous fine tuning of the construction process. Because of these factors, it is important to be able to quickly pinpoint what is wrong and to find a solution. A guide to this process of troubleshooting is provided in Tables 13-1 and 13-2, which identify some of the more common problems that the contractor or QC inspector may encounter during a project.

13.6.1 Troubleshooting Guide for Cold-In-Place Recycling

Table 13-1 Troubleshooting guidelines for partial-depth cold in-place recycling (CIR) operations. (ARRA 2001)

Problem	Typical Cause(s)	Typical Solution(s)
Flushing of asphalt at surface after laydown and before compaction	Excessive mix water	Reduce the target water content in the mix
	Excessive asphalt emulsion or recycling additive	Reduce asphalt content
	Inadequate mixing of materials	Hold the material in the mixing chamber longer Increase the blade processing to insure proper distribution of the recycling agent
Mix segregation	Inadequate asphalt coating of the aggregate due to inadequate water content in the mix	Increasing the water content in the mix or use softer grade asphalt in the emulsion
	Variation of existing materials	Add new graded base and redo mix design
Mat raveling after compaction	Too little asphalt emulsion (or recycling additive) in the mix	Increase the amount of asphalt emulsion or emulsified recycling additive in the mix Reprocess the problem areas
Shiny black mat after compaction	Too much asphalt emulsion or emulsified recycling additive in the mix	Reduce the amount of asphalt emulsion or emulsified recycling additive in the mix Reprocess the mix adding virgin material
Poorly graded RAP behind recycling unit and change in existing pavement	Variation in depth of existing materials	Add new graded base to keep constant depth and redo mix design
	Teeth on the milling machine are worn or broken	Change the teeth
	Speed of the operation is too fast	Slow the operation down
Variable depth	Poor control of grade	Repair (or use improved) grade controls
Varying dry and wet spots in RAP	Poor water and/or recycling agent control. Varying existing pavement and gradation changes	Check and calibrate pulverizing and mixing operations
Appearance of fines in RAP material	Milling into subsurface layers	Provide better control of depth. Confirm thickness of existing HMA layer
	Speed of the milling machine too slow	Increase speed of operation
Oversize RAP in the mix	Screen or breaker bar not functioning properly	Repair the screen or breaker bar
New mat stays spongy and/or will not densify	Steel wheel rollers may be sealing the top and causing moisture retention	Use a heavy pneumatic tire roller for breakdown and compaction rolling
	Excess moisture in mix	Confirm liquid contents in emulsion Revise target moisture in mix as necessary

13.6.2 Troubleshooting Guide for Hot-in-place Recycling

Table 13-2 Troubleshooting guidelines for hot in-place recycling (HIR) operations. (ARRA 2001)

Problem	Typical Cause(s)	Typical Solution(s)
Blue or black smoke emanating from the heating units or exhaust	Combustion and removal of hydrocarbons from the asphalt binder	Reduce the intensity of the heating units, raise the heating units from the pavement surface, or increase the forward speed of the heating units or employ additional heating units at a faster speed to allow heat to penetrate. Remove and replace the damaged areas with virgin mix.
Wet appearance of surface after recycling	Excess asphalt binder or recycling agent in mix	Check application rates of asphalt binder and recycling agent
Poor gradation of RAP	Speed of the operation too fast or too slow. Changes in existing pavement	Alter speed of the operation to minimize segregation and add heating units as needed to assure penetration depth is achieved
Variable or insufficient milling depth	Speed of the operation not correlated to the existing surface and ambient temperatures	Alter speed of the operation to match existing temperatures and add heating units as necessary to achieve proper depths
Inadequate density	Inadequate number of rollers, weight, passes, etc.	Check rollers for adequate weight, tire pressure, as well as rolling pattern
	Rolling when mix is too cold	Slow down the operation to allow the rollers to keep pace (or add additional rollers)
	Segregation	Slow down the speed of the operation to allow more time for proper mixing
Spot areas of flash fires or blue smoke	Excessive crack sealant and/or patches	Remove crack sealant prior to HIR operation
	Polymerized small maintenance patch areas	Remove patching material and, if necessary, replace with virgin HMA mix
Cannot achieve required depths of removal without producing blue smoke	Existing asphalt binder may have age hardened to a degree heat will not penetrate to the required depth without burning asphalt	Poor project for this construction method and may need to be canceled or specification requirements altered
Wet spots on the finished mat	Variation of the added asphalt binder or rejuvenating agent	Check and recalibrate the asphalt pump
	Excessive crack sealant	Remove crack sealant prior to operation
	Contamination of the existing surface	Remove contaminated areas and replace with HMA prior to processing
Dry spots in the finished mat	Variability of the added asphalt or rejuvenating agent	Check and recalibrate the asphalt pump

13.7 REFERENCES

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